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Summary Report

FEASIBILITY ANALYSES OF ELECTROEPITAXIAL R&D ACCOMMODATIONS

Volume I - Accommodations Assessment

April 1982

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BROWN ENGINEERING**

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SUMMARY REPORT
SP82-MSFC-2591

FEASIBILITY ANALYSES OF ELECTROEPITAXIAL
R&D ACCOMMODATIONS

VOLUME I

ACCOMMODATIONS ASSESSMENT

APRIL 1982



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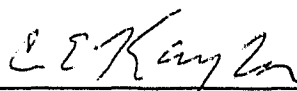
FOREWORD

A study to determine the feasibility of accommodating the R&D requirements of electroepitaxial crystal growth in the Space Shuttle has been performed. The specific accommodations facilities studied were the Orbiter Middeck stowage lockers, Materials Experiment Assembly (MEA), and Get Away Special (GAS) Cans. The effort has encompassed development of guidelines and assumptions necessary to quantify and characterize elements of the electroepitaxial process, conceptual design of a Gallium Arsenide Crystal Growth Facility, and assessment of facility requirements versus Orbiter Middeck, MEA, and GAS Can capability.

The results of this study indicates that the MEA can best accommodate the R&D furnace facility. The Middeck area, though marginally suitable, has energy, heat rejection, volume, and safety concerns. The GAS Can program ground rules prohibit its use for this application.

This study was performed by Teledyne Brown Engineering under Contract NAS8-34743.

APPROVED:



C. E. Kaylor
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1. INTRODUCTION

A preliminary assessment of the feasibility of accommodating the on-orbit R&D requirements for electroepitaxial crystal growth using the Orbiter Middeck, the Materials Experiment Assembly (MEA) or the Get-Away Special (GAS) Cans has been performed. The study is based on the proposed electroepitaxial growth of single crystals of Gallium Arsenide (GaAs). The study has encompassed establishing baseline R&D requirements, synthesizing furnace and facility conceptual design requirements, deriving accommodation requirements, and performing preliminary compatibility assessments. The systems engineering approach employed for the individual assessments is outlined in Table 1-1.

TABLE 1-1. ACCOMMODATIONS ASSESSMENT APPROACH

- | |
|--|
| <ol style="list-style-type: none">1. Determine furnace/facility requirements for baseline process/experiment2. Synthesize furnace/facility concepts/designs3. Define accommodation parameters (requirements): Estimates of mass, power, energy, cooling, volumes, hardpoints, safety, crew utilization, data and commands, etc.4. Develop inventory of resources of accommodations facilities5. Identify compatible/incompatible aspects<ul style="list-style-type: none">- Basic compatibility/incompatibility- Incompatibilities reconcilable with GFE- Incompatibilities reconcilable with redesign of furnace/facility (reasonable expectations) |
|--|

Since the proposed process is not yet completely defined and neither the R&D facility nor the on-orbit experiment designed, it has been necessary to establish baseline requirements and concepts for the study. These requirements and concepts were then assessed relative to the accommodations capabilities of the Middeck, MEA, and GAS Cans.

The information and data base developed by TBE in the study of Reference 1 were employed in establishing a baseline definition of the R&D requirements for the process. These sources were augmented by the data and information gained in a series of meetings and telecons among the participating organizations (Reference 2). The baseline requirements have been formulated as a list of guidelines and assumptions for the study (see Section 2-4).

The basic furnace/facility concept used in the study is a conceptual design developed by TBE which is adaptable to either Middeck or Cargo Bay applications. This design was undertaken to provide insight into the key issues and design drivers for an R&D scale facility for electroepitaxial growth of GaAs crystals. This design was adapted (conceptually) to each of the candidate accommodations locations/constraints to provide a basis for defining the levels of accommodations required (electrical, structural/mechanical, thermal, etc.).

The capabilities of the accommodations facilities were defined as follows:*

- Middeck: The standard capabilities of the Middeck as defined in Reference 3 were used without modification.
- MEA: The capabilities of MEA are assumed to be those of the MEA-A (Reference 4) with electrical/thermal modifications to permit use of Orbiter power/energy/cooling resources
- GAS Cans: Standard GAS Can characteristics (Reference 5) were employed.

The comparison of the accommodations requirements and the capabilities of the facilities focused on three aspects:

- Basic incompatibilities which are judged to preclude a given accommodations concept
- Incompatibilities that can be reconciled with Government Furnished Equipment to extend/augment the capabilities of the accommodations facility
- Incompatibilities that can be reconciled with reconfiguring or redesign of the crystal growth facility.

The latter aspect is important since marginal incompatibilities that can be accommodated by redesign are judged to be non-critical at this stage of process/facility concept development.

*The microgravity capabilities of the Orbiter were an exception and are discussed in terms of all three systems in the Conclusion.

2. PROCESS/EXPERIMENT

The electroepitaxial growth of single crystals of GaAs is discussed here in terms of basic characteristics and requirements, expected performance, and implementation for on-orbit operations. A more fundamental discussion of the process is given in Volume II. The process as currently understood and its applicability to on-orbit operations is based on on-going scientific research under the direction of Dr. Harry Gatos of the Massachusetts Institute of Technology.

2.1 Process Description

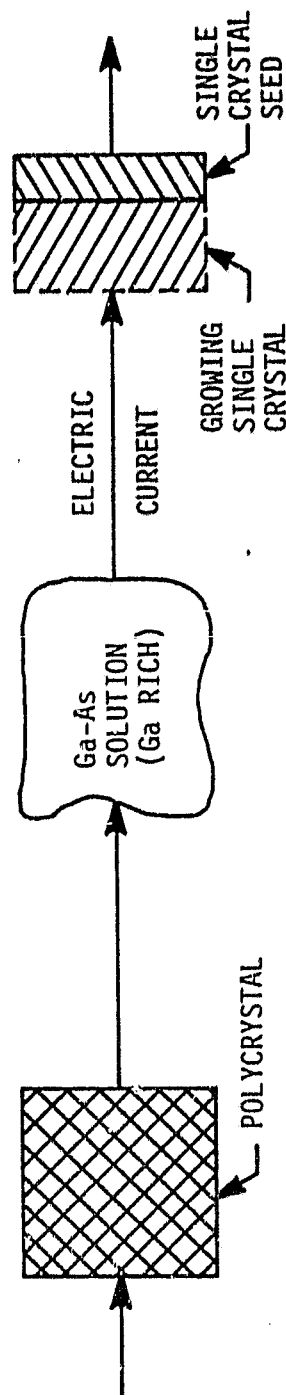
The proposed process is illustrated in Figure 2-1: A single crystal of GaAs* is placed in contact with a liquid-phase solution of Ga and As (rich in Ga) which, in turn, is in contact with polycrystalline GaAs. For appropriate temperatures and concentrations (of the solution) the passage of an electric current through the three elements (from the polycrystal to the single crystal) results in an orderly deposition of GaAs onto the single crystal with a net increase in its bulk and worth.

The basic assembly of single crystal/solution/polycrystal is called a cell. The elements have a common cross-sectional area and are housed in a non-conducting structure with appropriate electrical connections.

The temperature-solution concentration values for the process are based directly on the conditions used in the laboratory studies, i.e., temperatures of 850 to 900 °C and As concentrations of less than 10% (atomic basis). The exact combination to be used is TBD, but the selection of either parameter defines the other in order that the combination occur on the locus of points separating the regions of liquid equilibrium from solid-liquid equilibrium. This condition is defined in the simplified composition diagram of Figure 2-2.

The polycrystalline GaAs is the raw material for the process. Basically, the deposition of GaAs onto the single crystal disturbs the equilibrium of the solution which is spontaneously reestablished by

*Unless specified otherwise, GaAs refers to appropriately doped crystals.



• ADVANTAGES

- RELATIVELY LOW TEMPERATURE FOR GaAs GROWTH (850-950 °C)
- ISOTHERMAL PROCESS
- GROWTH RATE PROPORTIONAL TO ELECTRIC CURRENT

• DISADVANTAGES

- UNPROVEN FOR LARGE CRYSTALS
- SLOW GROWTH
- NOT REASONABLE FOR RESISTIVE CRYSTALS

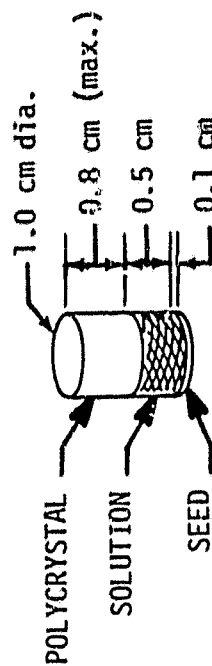


FIGURE 2-1. ELECTROEPITAXIAL GROWTH OF GaAs SINGLE CRYSTALS

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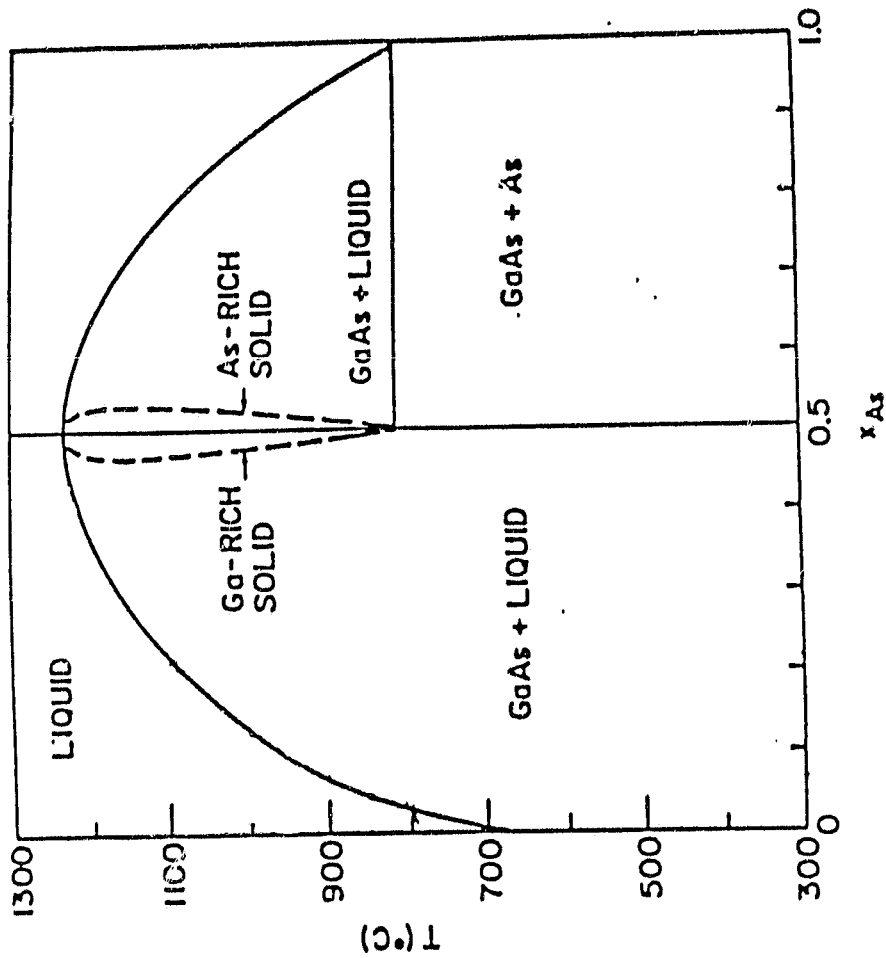


FIGURE 2-2. CONDENSED PHASE TEMPERATURE-COMPOSITION DIAGRAM
OF THE Ga-As SYSTEM

dissolution of the polycrystal. At the macroscopic scale, the dissolution rate of the polycrystal equals the growth rate of the single crystal. A seed of single crystal is used as the starting base for growth.

A sketch of a laboratory-type furnace for the process is shown in Figure 2-3. This facility differs from intended facility in that the laboratory device does not include a polycrystalline source and the solution is used as a limited source. However, the sketch does illustrate materials and techniques successfully employed in the electroepitaxial growth of GaAs and which have been assumed applicable for on-orbit processing.

2.2 GROWTH RATE

The growth of the single crystal is normal to its face in contact with the solution and, for uniform distribution of the current across the face, the growth in this normal dimension is also uniform across the face. Based on the available data, the linear growth rate is proportional to the current density. Numerically, the data indicate a proportionality of 0.12 $\mu\text{m}/\text{min}$ per A/cm^2 at 900 °C for laboratory experiments (this value can also be stated as $0.12 \times 10^{-4} \text{ cm}^3/\text{A-min}$).

Information provided by Dr. Gatos [Reference 2(G)] indicates that the proportionality is not valid for growth rates less than about 1 $\mu\text{m}/\text{min}$ because of dissolution of the single crystal.

Confirmation of the proportionality, its magnitude and any limits will be required in the R&D activities.

Assuming the proportionality to be valid for on-orbit processing yields a growth-current relationship of the form:

$$\dot{\lambda} = GI/A$$

where $\dot{\lambda}$ = rate of growth normal to face of crystal

I = electric current magnitude

A = cross-sectional area

G = proportionality constant.

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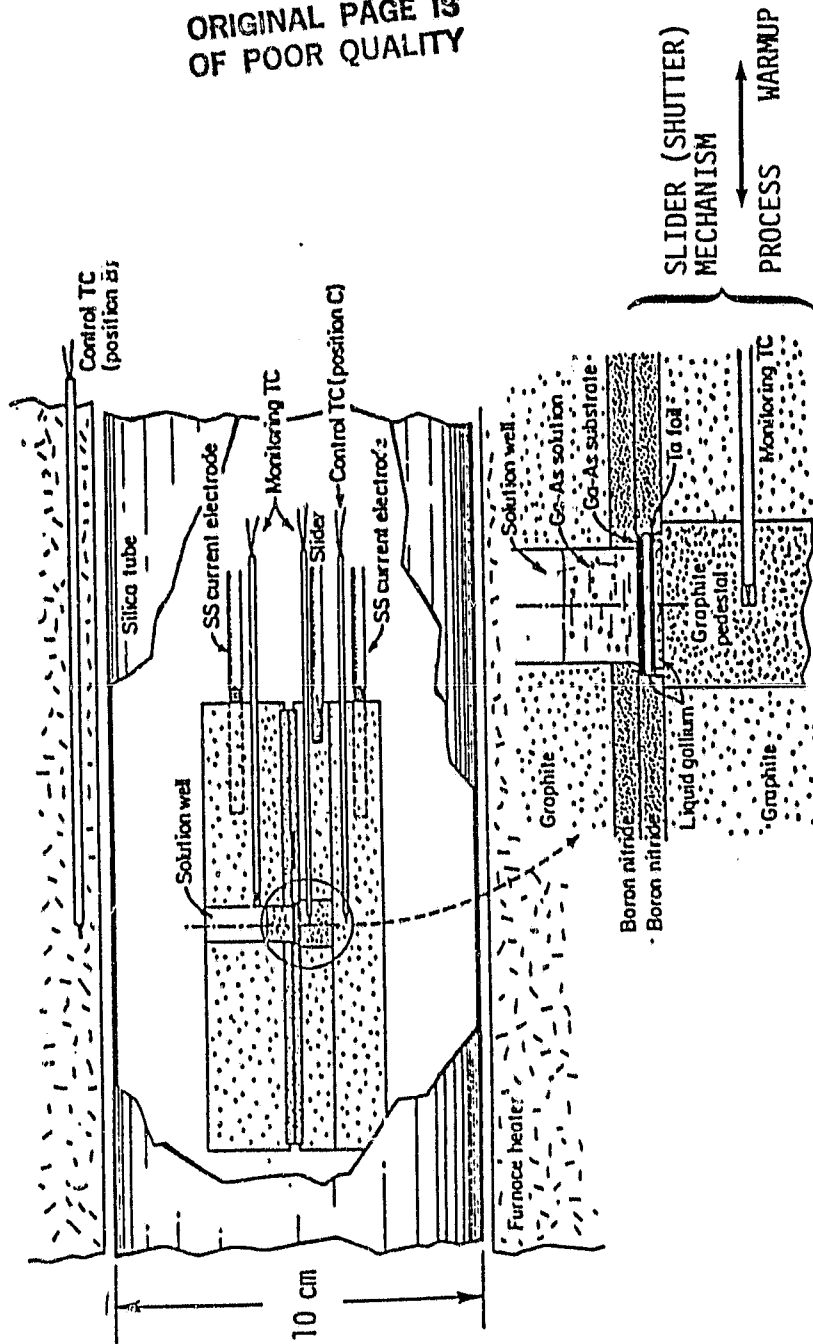


FIGURE 2-3. LABORATORY FURNACE

2.3 SEED/SOLUTION ISOLATION

It will be noted that the laboratory facility of Figure 2-3 has a shutter mechanism which contains the seed. The purpose of the shutter is to permit physical isolation of the seed from the solution during warmup/melting phases. Laboratory experience indicates that the seed can be damaged if exposed to the solution prior to processing. The shutter positions the seed in the electrical path in contact with the solution following the warmup/melting cycle.

2.4 GUIDELINES AND ASSUMPTIONS

The primary objective of the on-orbit R&D activities for the proposed process will be the growth on orbit and return of single crystals to provide data for confirmation of expectations, for tuning of the process and for verification of implementation/mechanization schemes. This objective will require the design of an on-orbit experimental program which will grow crystals of sufficient size and quantity, which will address design issues not resolvable in ground tests, which will provide sufficient types and quality of measurements, etc. Since this level of detail does not exist, to accomplish the study it has been necessary to establish baseline requirements for an R&D program for the process based on available data and information.

Therefore, the first effort of the study was the derivation of baseline requirements. The result is presented in Table 2-1 as an itemized list of guidelines and assumptions for the process and the experiment. The data bases of References 1 and 2 were the sources for these items.

The primary issues/considerations for these items are as follows:

1. Growth Rate Constant: The basis for the $0.12 \times 10^{-4} \text{ cm}^3/\text{A-min}$ value used in the study is given in Volume II. Essentially, this value is the slope obtained from experiments for which rate of growth versus current density are available (at 900 °C). The confirmation/update of this value is a primary object of the on-orbit R/D (experiment) program and of preflight ground tests.

TABLE 2-1. ASSUMPTIONS/GUIDELINES FOR ELECTROEPITAXIAL PROCESS
FOR ACCOMMODATIONS ASSESSMENTS

1. Growth rate constant of $0.12 \times 10^{-4} \text{ cm}^3/\text{A-min}$
2. GaAs (Single crystal/polycrystal) resistivity of $0.03 \Omega\text{-cm}$
3. Grow 1 cm diameter single crystal
4. Growth rate of $1.0 \mu\text{m/min}$ minimum to minimum crystal length of 0.5 cm or to maximum of 0.7 cm .
5. Seed (initial) dimension of 0.1 cm (thickness)
6. Design goal of 4 days processing time including warmup/cool-down
7. Provide furnace processing zone sufficient in volume for three growth cells
8. Provide pre-process seed isolation
9. Provide 25% margin for energy/power relative to accommodations
10. Cell temperature of 900°C
11. Spatial temperature differences within cell of less than $\pm 0.1^\circ\text{C}$
12. Temporal changes of cell temperature of less than 2°C/hr within $\pm 5^\circ\text{C}$ control band are acceptable
13. Acceleration levels of 10^{-5} g .

2. Crystalline Resistivities of GaAs (0.03 Ω -cm): The resistivity of the crystals is important in that it influences the power/energy requirements for the process. The value for the single crystal is taken from Reference 2(I). The value given represents doped, single crystal GaAs at the temperature of concern (850-900 °C). This same value is used for the polycrystal as being conservative and consistent with available data.

In the present state of development, the resistivity of the polycrystal is not a major concern since it appears to be feasible to control the net resistance of the polycrystal to some extent by appropriate shaping.

3. Crystal Diameter (1 cm): The selected diameter represents a qualitative tradeoff of size and power/energy/package considerations. The 1 cm diameter is judged to be large enough for experimental purposes yet small enough to be potentially accommodated in an R/D scale facility.
4. Minimum Growth Rate/Length: The minimum growth rate to be considered (1 μ m/min) is based on potential problems at lower rates. Specifically, it is possible for the single crystal to dissolve faster than it is growing if the growth rate is below 1 μ m/min. The ranges for the length to be grown represents what is expected to be reasonable for experimental purposes.
5. Seed (Initial) Dimension (0.1 cm): This dimension is based on inputs by MIT [Reference 2(I)].
6. Net Processing Time (4 Days): The goal of having a net processing time of four days is intended as an upper limit in order to sustain manifesting flexibility.
7. Number of Processing Cells: Three processing cells have been judged as the minimum number which, on a per mission basis, will yield sufficient replication/test points for overall experimental purposes.

8. Preprocessing Seed Isolation: Physical isolation of the seed from the solution during the warmup/melting for the process is incorporated in the laboratory experiments which form the basis for the proposed process. It is assumed that a similar feature will be incorporated into an on-orbit facility.
9. Energy/Power Margins (25%): The objective of this guideline is to avoid overstressing of accommodations.
10. Cell Temperature (900 °C): Single value chosen to avoid unwarranted parameterization (at present state of development). Specific value is chosen as being most conservative.
11. Spatial Temperature Gradient (± 0.1 °C): Baselined to highlight thermal control concerns. Value from Reference 2(I).
12. Temporal Temperature Changes (± 5 °C and 2 °C/hr): Baselined to highlight temperature control concerns.
13. Acceleration Levels less than 10^{-5} g: Baselined as experimenter requirement. Will impact instrumentation/recording system and orbiter operations/constraints.

In the course of the analysis it proved necessary to make further assumptions for issues which were unforeseen and which evolved from specific design and accommodations issues. These additional assumptions are given in Table 2-2 which also notes the paragraph in which the assumption is cited or whether the assumption is applicable to all phases of the study.

2.5 PROCESS POWER/ENERGY LEVELS

The process energy for the electroepitaxial growth of single crystals of GaAs is defined as the energy dissipation in the cell (polycrystal/solution/single crystal). At the macroscopic level, this energy is almost exclusively the Joule heating (I^2R -type) which occurs in the polycrystal and single crystal as a result of the passage of the electric current. Little dissipation occurs in the solution because it is much more conductive than the solid crystals.

TABLE 2-2. ADDITIONAL ASSUMPTIONS EMPLOYED IN THE
ACCOMMODATIONS ASSESSEMENT

1. MEA capabilities defined by Reference 4 with use of Orbiter Power/Cooling (Section 1)
2. Materials used in laboratory equipment for GaAs growth is assumed suitable for on-orbit use (paragraph 2.1)
3. Residual (post-growth) polycrystal thicknesses of 0.14 cm (paragraph 2.5)
4. Bulk density of polycrystalline and single crystal are assumed equal (paragraph 2.5)
5. The thermal equilibration of seed and solution (following shutter motion) is assumed to require no more than 15 min (paragraph 3.1)
6. The voltage characteristics of the Cargo Bay as defined in Reference 6 are used as generic data for all Orbiter locations (paragraph 3.4.2)
7. DC-to-DC Converter Efficiencies are assumed as follows (paragraph 3.4.2):
 - A. Downward conversion of voltage/upward conversion of current: 60%
 - B. Downward conversion of voltage/current: 80%
8. The use of Ga wafers at intra-furnace conduction joints is assumed to reduce the interface resistance to minimal levels (paragraph 3.5.3)
9. Mass of electronics for facility is estimated to be that for the Monodisperse Latex Reactor with an additional 50% margin (paragraph 3.5.4)
10. Electronic cooling criteria are assumed as follows:
 - A. Case Cooling (radiation/low-g convection/conduction)
Maximum: 0.18 W/in²
Minimum: 0.09 W/in²
 - B. Cold Plate Cooling: 1.5 W/in²
11. It is assumed that acceleration measurement and data recording will use GFE (paragraph 4.2.4)
12. Data processing is assumed to be required only during the actual processing, and downlinking of data is assumed not to be required (paragraph 4.2.4)

The resistance of either of the two crystals in any individual cell is given by

$$R = \frac{\rho l}{A}$$

R = resistance

l = depth of crystal normal to cross-sectional area

A = cross-sectional area

ρ = resistivity

For the cells defined by the guidelines and assumptions (diameter = 1.0 cm, seed thickness = 0.1 cm, $\rho = 0.03 \Omega\text{-cm}$)* the resistance as a function of growth length are:

<u>Growth Length (cm)</u>	<u>Resistance (Ω)</u>
0.5	0.0284
0.6	0.0322
0.7	0.0361

The minimum current density of interest is some 8.33 A/cm^2 corresponding to the minimum growth rate of $1 \mu\text{m/min}$. The voltages/power dissipations at this current density and higher levels of interest (to some 24 A/cm^2) are as follows for the 0.0361Ω resistance of the 0.7 cm growth length:

<u>Current Density</u> (A/cm^2)	<u>Voltage Drop</u> <u>Across Cell (V)</u>	<u>Power Dissipation</u> (W)
8.33	0.300	2.50
12	0.432	5.19
16	0.576	9.23
20	0.721	14.4
24	0.865	20.8

The voltages and power dissipations must be tripled for the R&D configuration of 3 cells.

These values indicate the power requirements for the process, as such, are relatively small. Power requirements for thermal management, losses, etc. are discussed in the context of the facility design and the individual accommodations assessment.

*Additionally, a residual polycrystal thickness of approximately 0.14 cm is assumed.

At a current density of 24 A/cm², a growth length of 0.7 cm and the limiting assumption that all of the targeted 96 hours is used for processing yields an upper limit on processing energy of some 6.0 kW. This energy level is relatively low compared to facility power requirements as will be shown.

The bulk density of the single crystal and the polycrystal are essentially equal (5.32 g/cm³). Therefore, when the cells are packaged as cylinders (right circular, rectangular, etc.) on a common axis with the solution sandwiched between, the net length of solid material in the cell (polycrystal plus single crystal) remains constant during the growth process. Mathematically,

$$\frac{d}{dt} (\ell_p + \ell_s) = 0$$

where t = time

ℓ_p = length of polycrystal

ℓ_s = length of single crystal

Process time as a function of current density for growth lengths of 0.5, 0.6 and 0.7 cm is shown in Table 2-3.

TABLE 2-3. PROCESS TIME REQUIREMENTS

CURRENT DENSITY (A/CM ²)	GROWTH RATE (μM/MIN)	GROWTH TIME (HR)		
		0.5 CM GROWTH	0.6 CM GROWTH	0.7 CM GROWTH
8.33	1.0	83	100	117
12.0	1.4	58	69	81
16.0	1.9	43	52	61
20.0	2.4	35	42	49
24.0	2.9	29	35	41

NOTE: GROWTH RATE CONSTANT = 0.12×10^{-4} CM³/A-MIN

3. FURNACE/FACILITY DESIGN HIGHLIGHTS

The conceptual design presented here was undertaken by TBE in order to define design-level feasibility issues and drivers associated with implementing the electroepitaxial process in an R&D scale facility. The approach was to undertake a design suitable for the Middeck and which by adaptation could be used in the Cargo Bay (as a MEA, GAS Can or a stand-alone facility). The characteristics of the resulting design are presented here to provide a basis for the accommodations assessment.

The basic requirements for the process and experiment have been taken as the guidelines and assumptions of Table 2-2. The Orbiter accommodations (Middeck), requirements, and constraints were taken from References 3, 6, and 8, respectively.

3.1 FACILITY ELEMENTS

The facility envisioned for implementing the electroepitaxial process on an R&D scale is shown in the block diagram of Figure 3.1. The facility is seen to consist of the furnace and a number of functional subsystems necessary to provide the interfaces and interface control with the Orbiter and for control and data management of the process itself. It is expected that the actual "black box" type packaging of these elements will combine similar functions. The basic functions of the elements are described in Table 3-1.

The GFE for the facility will include any non-standard services required for Orbiter accommodation (e.g., cooling loop, pump, pump controller) and possibly accelerometer/data recorder.

Operation of the Furnace involves four basic modes:

- Standby ~ checkout and verification mode
- Warmup ~ heatup up mode
- Equilibrate* ~ a brief interval after shutter actuation to achieve final thermal stabilization
- Process ~ the actual growth mode

*The assumption is that equilibration will require no more than 15 minutes.

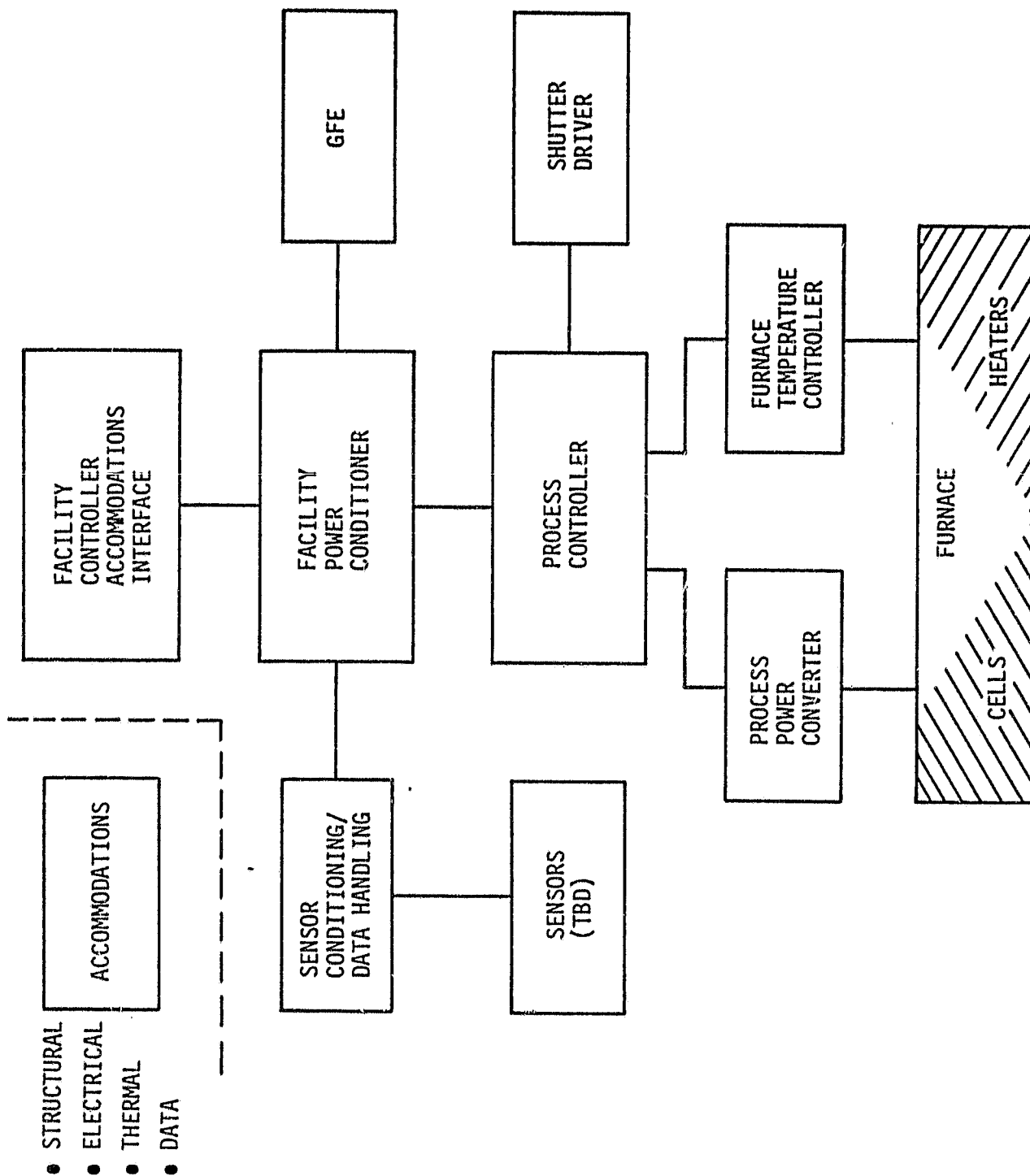


FIGURE 3-1. ELEMENTS FOR R&D FACILITY

TABLE 3-1. SUBSYSTEM FUNCTIONS FOR THE R&D FACILITY

SUBSYSTEM	FUNCTION
Furnace	Provides cell materials containment and the process environment. Furnace encompasses process power distribution to cells, main, trim and environmental heaters, temperature sensors, seed/solution isolation shutter, and hi-temperature and bulk insulation.
Furnace Temperature Controller	Provides temperature control of the process zone to accuracy requirements. Redundant sensors provide feed-back loop control of main and trim heaters.
Process Power Converter	Provides power conversion capability to increase amperage of accommodations power supply.
Process Controller	Provides sequencing control through standby, warmup, equilibration, processing, and cooldown. Includes Shutter operation commands.
Shutter Driver	Provides energy for operating isolation shutter mechanism. Includes pneumatic supply, valve/regulator assembly and relief valve.
Facility Power Conditioner	Provides all power conditioning required for the furnace facility.
Sensor Conditioning/ Data Handling	Provides all I/O signal conditioning and data handling functions/interfaces.
Sensors	Provides scientific/process measurements. Includes temperature, pressure, events, current levels, acceleration, etc.
Government Furnished Equipment (GFE)	Includes batteries, tape recorders, etc., which are required to complete the facility.
Facility Controller Accommodations Interface	Provides the highest level control/management of the subsystems and functions. Includes accommodation interface (electrical, CDMS, control panel, fusing, switching, etc.)

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3.2 FURNACE DESIGN

The basic furnace concept is shown schematically in Figure 3-2. A heated core which contains the processing cells is surrounded by layers of insulation and is double sealed by inner and outer containers. The outer container also functions as a vacuum jacket for the Middeck application to improve insulation performance. The items included in the furnace core are shown schematically in Figure 3-3 which also shows the arrangement of the cells.

A partial list of the factors considered in the design of the furnace are given in Table 3-2.

3.2.1 FURNACE CELL

The design of the furnace core is illustrated in Figure 3-4. The core consists of two matching Boron Nitride (BN) pieces with machined and drilled passages for electrodes, thermocouple, heater wire, the cells, etc. The split construction permits assembly of the core and the other elements.

Boron Nitride, which is non-conducting, is adopted from the laboratory furnace of Figure 2-3. The furnace core, once assembled, is approximately 2.6 in. (diameter) by 5.0 in. (height).

3.2.2 Seed/Solution Isolation

The basic approach to seed/solution isolation is also adopted from the laboratory furnace. The approach is illustrated in Figures 3-4 and 3-5. A single shutter containing the three seeds is positioned to isolate the seeds during the warmup process.

In this design, the shutter is gas-driven. This mode was selected for the Middeck to permit layout/routing flexibility. As will be shown, the furnace assembly exceeds 20 in. in height and an electromechanical type drive would impose an (estimated) 8 in. to 16 in. of additional assembly height.

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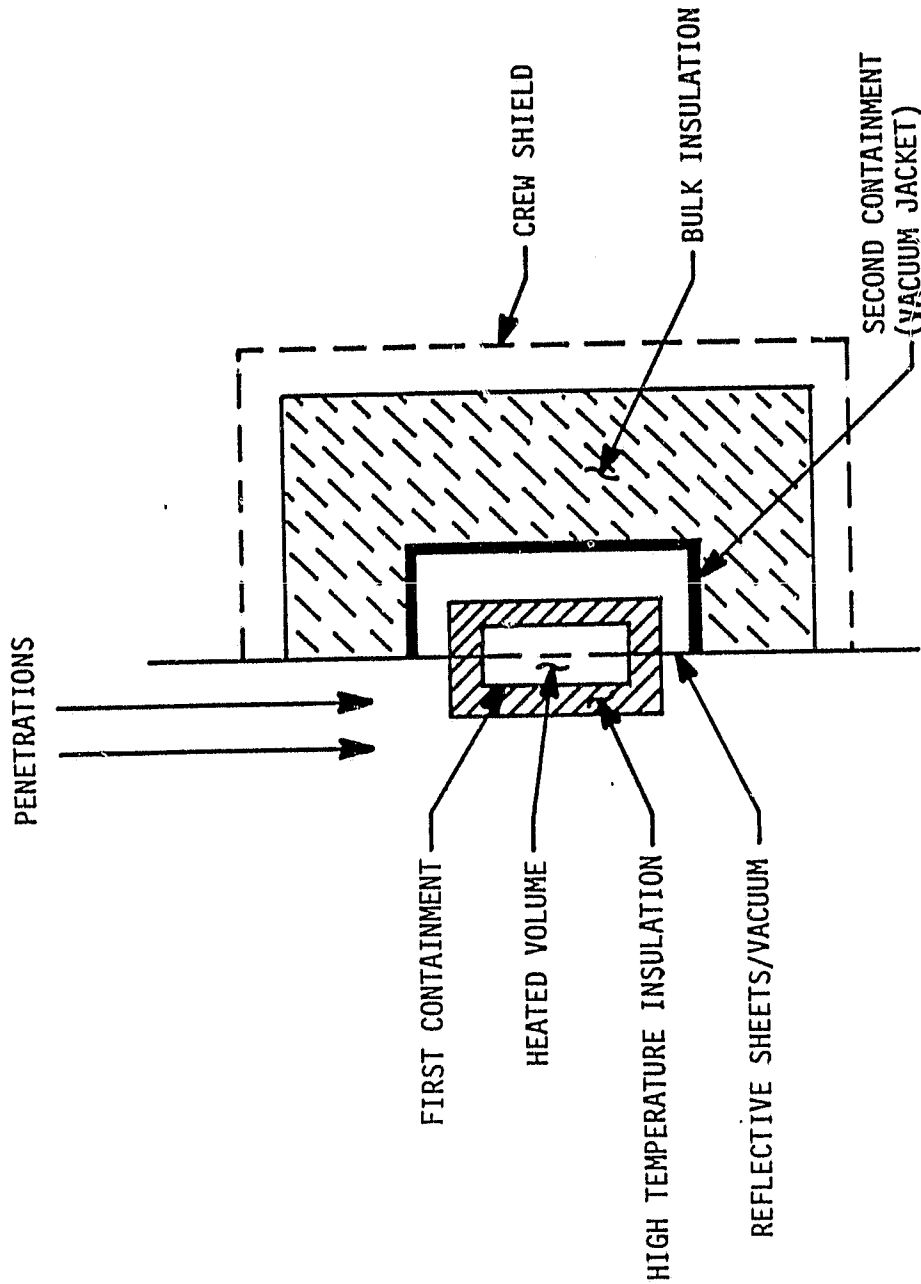
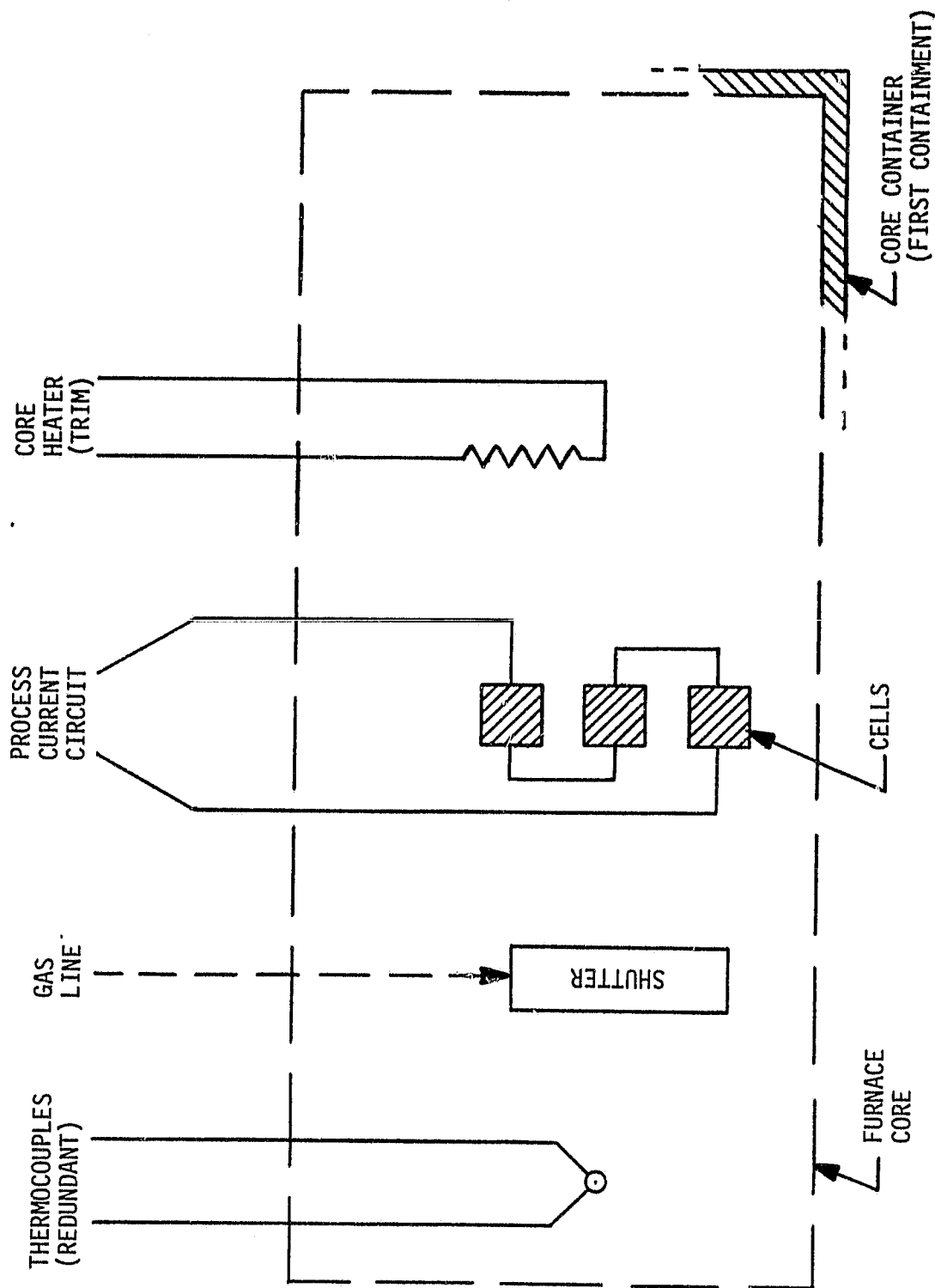


FIGURE 3-2. BASIC FURNACE CONCEPT

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NOTE: SEED/SOLUTION ISOLATION IS NOT INDICATED.

FIGURE 3-3. FURNACE CORE SCHEMATIC

TABLE 3-2. FURNACE DESIGN REQUIREMENTS

- PROCESS
 - SEED/SOLUTION ISOLATION
 - ISOTHERMAL PROCESSING ZONE
 - HIGH TEMPERATURE (850 TO 900 °C)
 - LOW PROCESS PRESSURE ($<10^{-5}$ ATMOSPHERES)
 - TEMPORAL TEMPERATURE VARIATIONS
 - ELECTRIC CURRENT
 - THREE 1.0 CM DIA. SPECIMENS
- SAFETY
- ASSEMBLY/DISASSEMBLY
- MANUFACTURABILITY
- STRUCTURE/MOUNTING/ENVELOPES
- PENETRATIONS
 - INSTRUMENTATION
 - POWER (PROCESS/HEATERS)
- MINIMAL POWER/ENERGY

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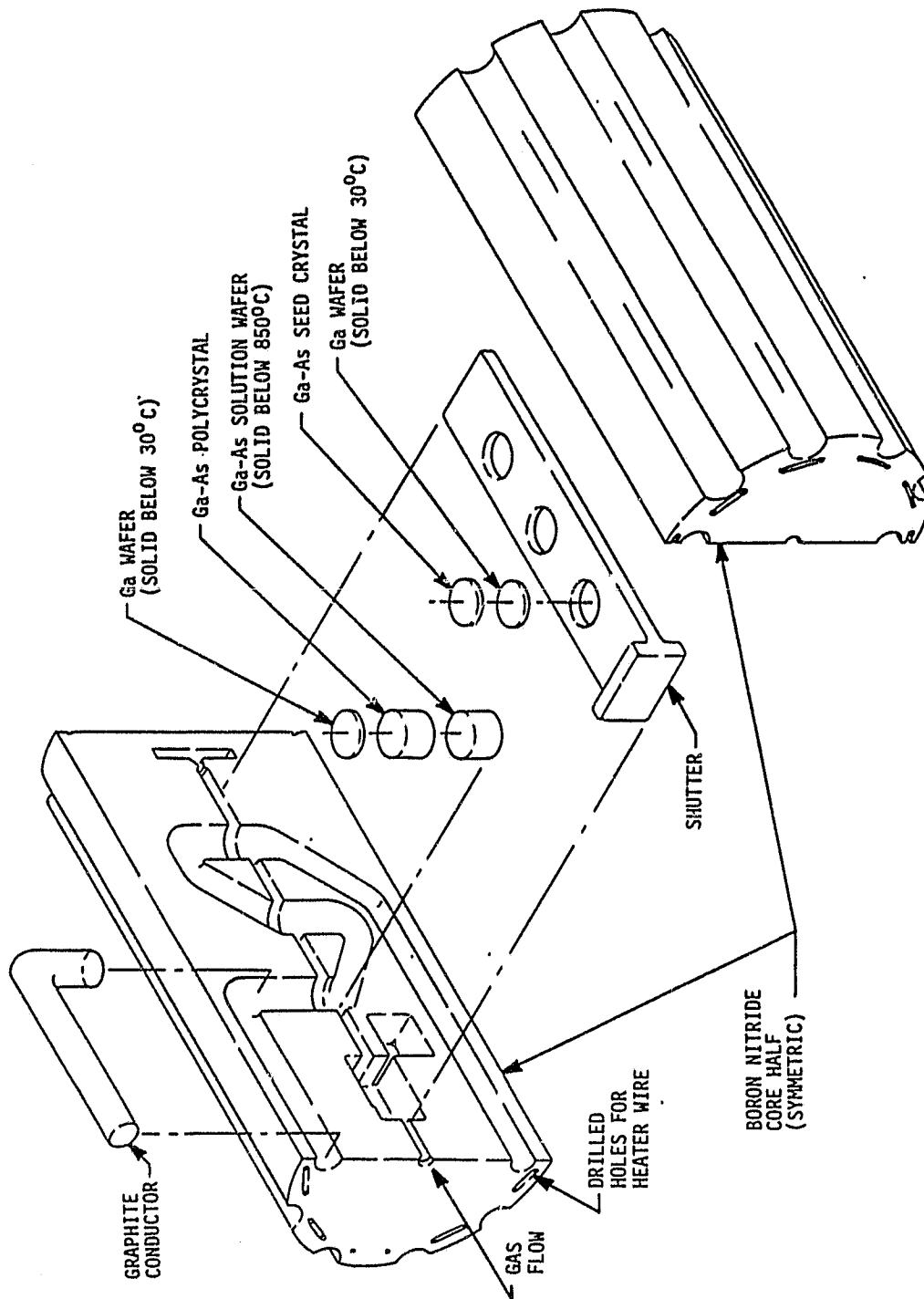


FIGURE 3-4. FURNACE CORE DESIGN

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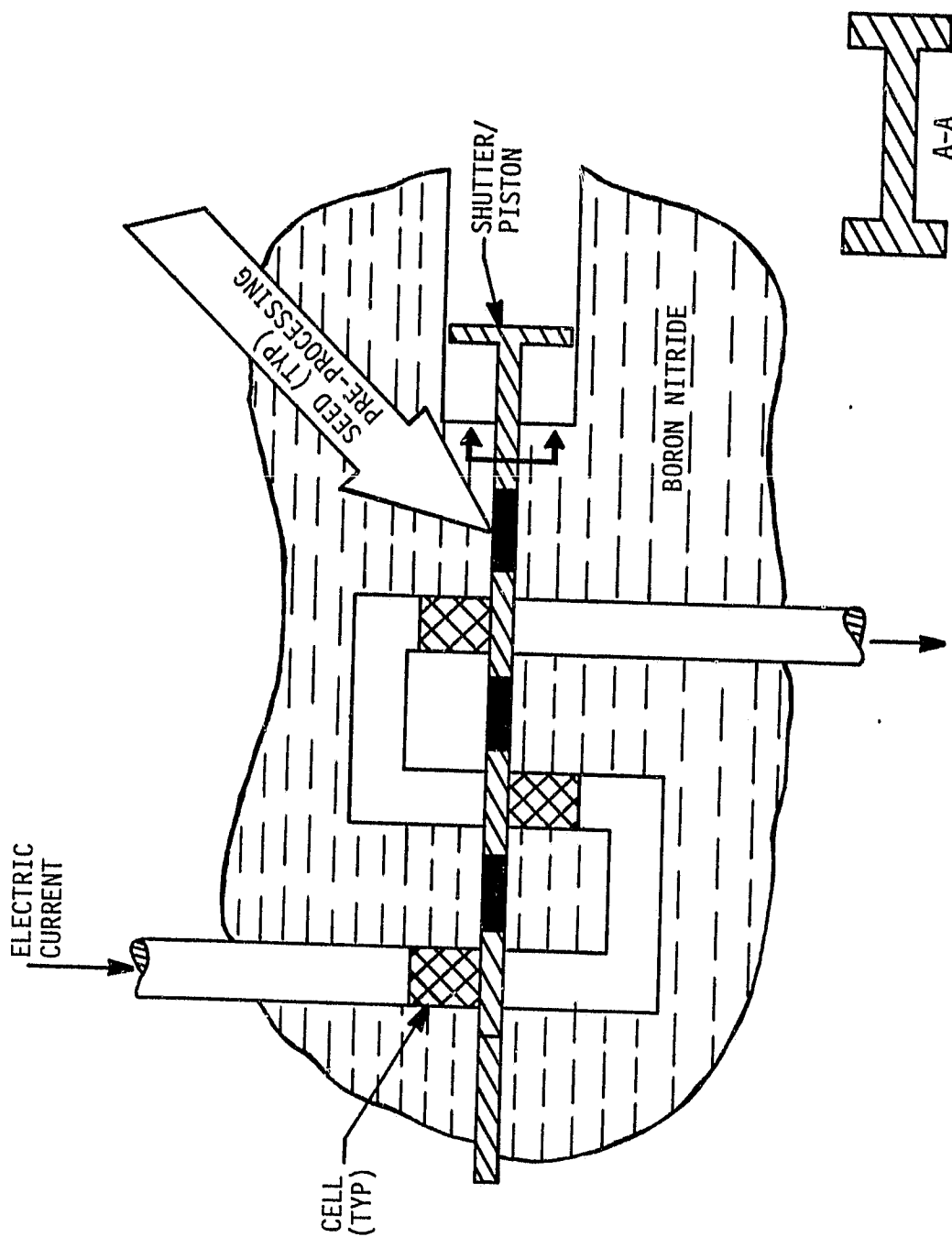


FIGURE 3-5. SEED/SOLUTION ISOLATION TECHNIQUE

3.2.3 PROCESS POWER DISTRIBUTION

The requirements for the process power distribution are given in Table 3-3. The conceptual design employs molded graphite conductors as shown in Figure 3-4 with Ga wafers at the graphite/polycrystal and single crystal/graphite interfaces. The Ga wafers melt under operating conditions and provide reduced electrical resistance at the joints.

The external conductors are embedded in the graphite.

3.2.4 HEATERS

As shown in the functional diagram of Figure 3-6, at least three heaters will be required: primary, warmup and trim. The trim and warmup heaters are located in the drilled holes shown in Figure 3-4. The primary heater will be located externally to the core and its containment to relieve the spacing problem at the end of the core assembly.

3.2.5 CONTAINMENT/SUPPORT

The basic approach to furnace support and the double containment approach to safety is shown in Figure 3-7. The two core halves (with the cells, electrodes, etc. in place) are mated and inserted into the first containment.

The first containment is end-mounted to a conically-shaped structure which has the end-caps for the two containments at either end.

3.2.6 INSULATION PROFILE

The insulation profile for the furnace is shown in Figure 3-2 and Table 3-4. The high temperature and reflective insulations are located between the two containments. This volume is passively evacuated to provide enhanced insulation performance. The bulk insulation is located externally to the second containment.

Differing types of insulation are used in order to provide flexibility for temperature service and thermal performance while satisfying manned spacecraft standards. No single type of insulation has been identified which is suitable and effective for all of the temperature ranges encountered in the design.

TABLE 3-3. PROCESS POWER DISTRIBUTION REQUIREMENTS

REQUIREMENTS

- PROVIDE PROCESS CURRENT TO CELLS IN SERIES
- PROVIDE DISTRIBUTION CIRCUIT-TO-CELLS CONTACTS
- MINIMAL DISTRIBUTION LOSSES
- PROVIDE LAYOUT/ASSEMBLY/DISASSEMBLY FLEXIBILITY
- MATERIALS COMPATIBILITY

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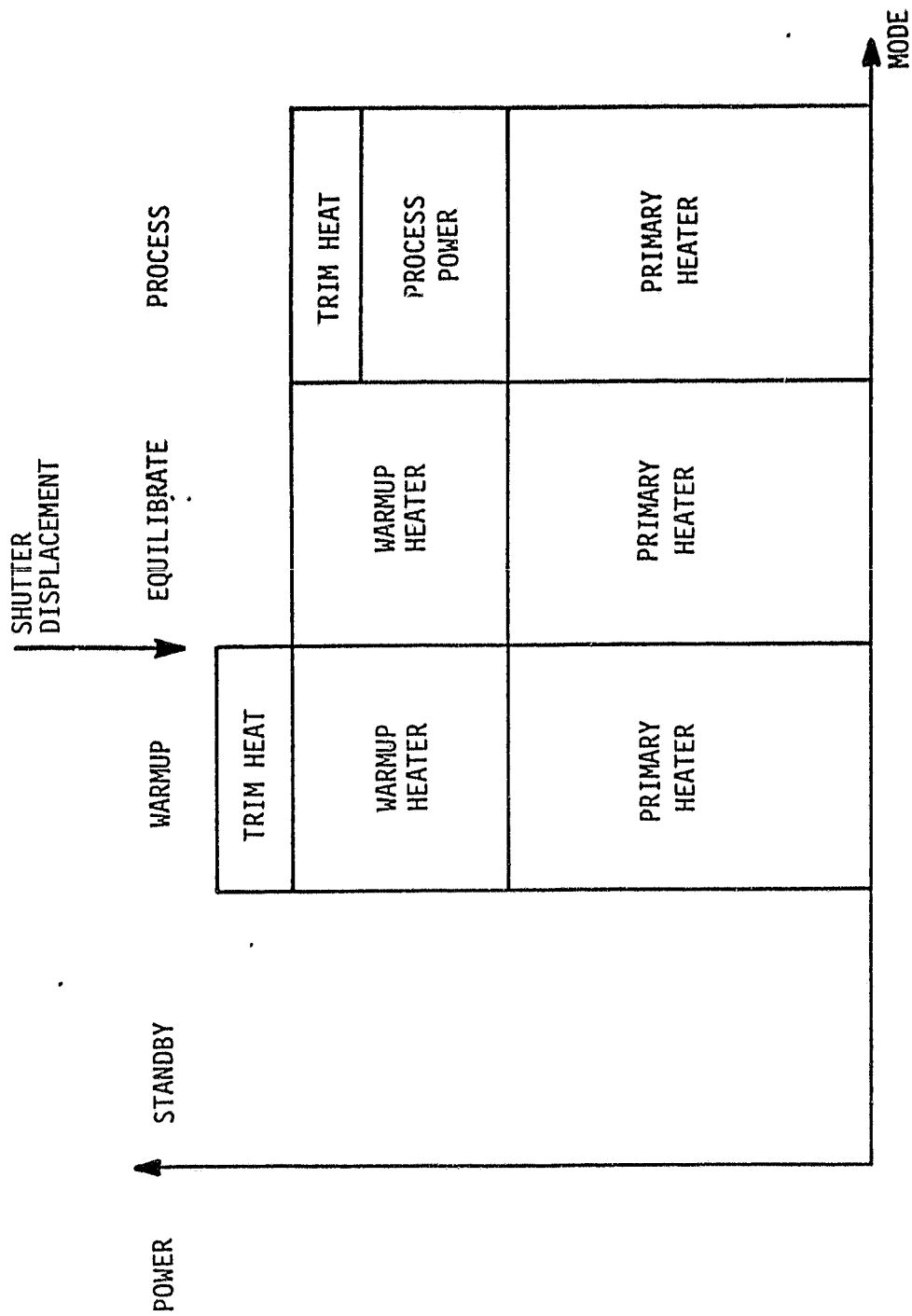


FIGURE 3-6. FUNCTIONAL DIAGRAM FOR HEATERS

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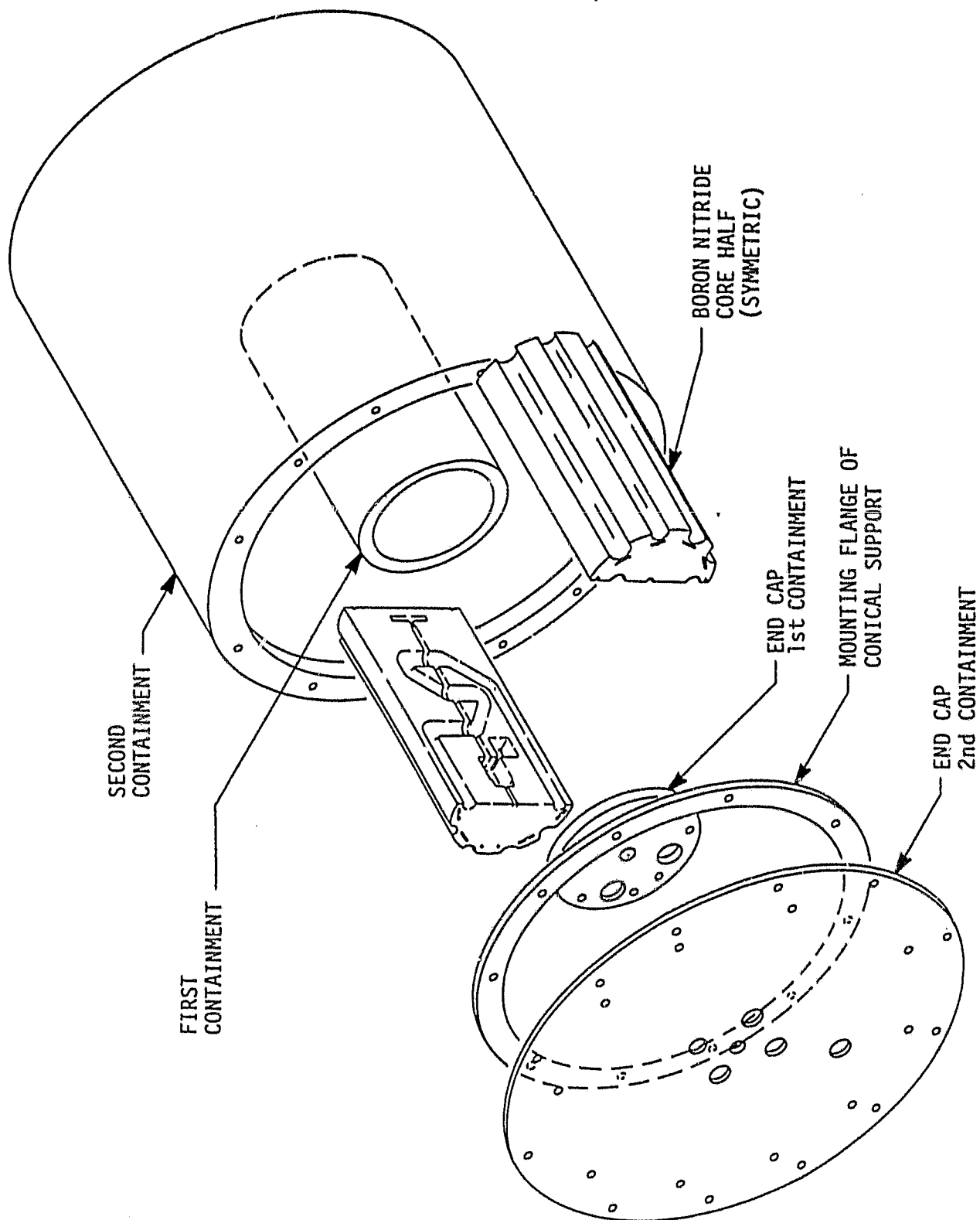


FIGURE 3-7. DOUBLE CONTAINMENT/STRUCTURE CONCEPT

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TABLE 3-4. MIDDECK INSULATION PROFILE

INSULATION	THICKNESS
HIGH TEMPERATURE	2 IN.
REFLECTIVE	1 IN.
BULK INSULATION	3 IN.
AIR GAP	1.5 IN.
HEAT LEAKS @ 900°C (W)	
SIDEWALL/ENDS	200*
PENETRATIONS/SUPPORTS	<u>100**</u>
TOTAL WATTS	300

*COMPUTER SIMULATION

**HAND CALCULATIONS

3.2.7 CREW SHIELD

An early conceptualization of the facility is shown in Figure 3-8. As noted on the sketch, the crew shield is the outermost surface of the furnace and it is the surface which the crew can touch. In order to maintain this surface at less than 45°C as required for safety purposes, a perforated screen will be employed.

By adjusting the air gap depth between the shield and the bulk insulation and the open area, it is possible to obtain reduced temperatures on the shield. Additional control is possible through selection of the optical properties of the shield (low emissivity on the furnace side and high emissivity on the cabin side).

Overall, the crew shield (18 in. diameter x 21 in. height) defines the envelope for the furnace.

3.3 FURNACE SAFETY

The hazards associated with the furnace (for a Middeck application) are given in Table 3-5. The basic controls for these hazards to satisfy Reference 8 are described in the following paragraphs.

3.3.1 TOXIC SUBSTANCES (GALLIUM/ARSENIC)

The Gallium/Arsenic compounds will be doubly contained. Containments will not be opened during any STS operations.

3.3.2 ELECTRICAL SHORT/SHOCKS

Appropriate materials, fusing, grounding and interlocking will be employed to preclude electrical hazards.

3.3.3 FURNACE OVERTEMPORATURES

The design will employ overtemperature sensors to initiate safing of furnace. This mode of control will be in addition to overtemperature sensing/safing built into the functional controller.

3.3.4 MISSION ABORT

Safety critical furnace and structural elements will be designed for safe reentry/landing operations under abort conditions through temperature specifications for materials selection.

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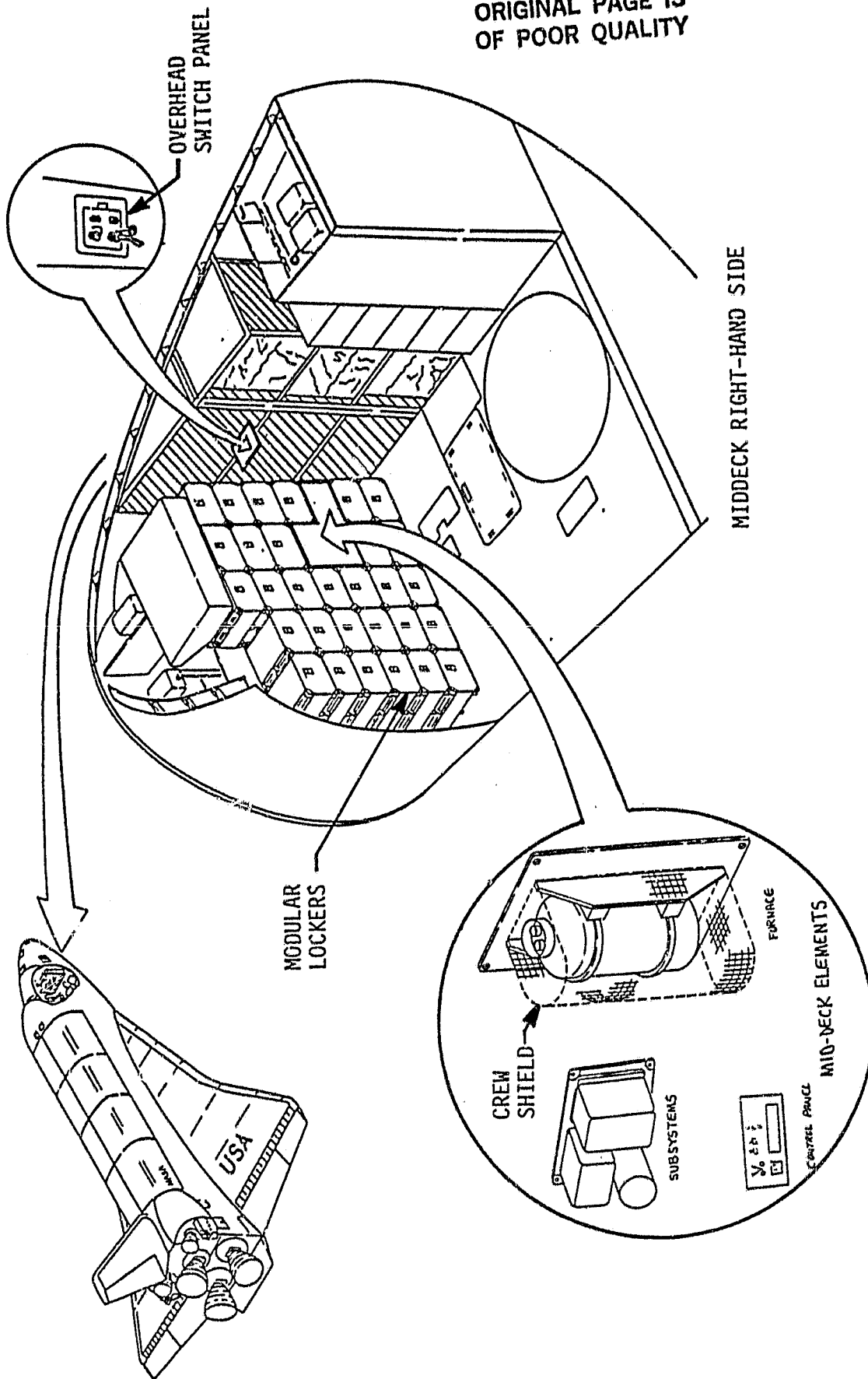


FIGURE 3-8. FACILITY/MIDDECK CONCEPTUALIZATION

TABLE 3-5. FURNACE SAFETY

HAZARDS

- TOXIC SUBSTANCES (GALLIUM/ARSENIC)
- ELECTRIC SHOCK/SHORT
- FURNACE OVERTEMPERATURE ABOVE DESIGN
(950 °C + MARGIN)
- MISSION ABORT WITH HOT FURNACE STRUCTURES (DEGRADED STRUCTURAL
MATERIAL PROPERTIES)
- ARSENIC OVERPRESSURES (As SUBLIMES ABOVE 615 °C RESULTING
IN VAPOR PRESSURE GENERATION)
- CREW EXPOSURE TO HOT SURFACES

3.3.5 ARSENIC OVERPRESSURES

Arsenic in uncombined form will be prohibited.

3.3.6 CREW EXPOSURE TO HOT SURFACES

The crew shield will be designed to yield safe exposure temperatures.

3.4 FACILITY DESIGN

In addition to the furnace, key elements of the facility design include temperature control, power conditioning/conversion and the shutter driver.

3.4.1 TEMPERATURE CONTROL

The temperature control for the furnace involves three factors: control bandwidth about the setpoint; gradients within the furnace; and temperature stability. The type of control to be employed is illustrated in Figure 3-9.

The requirements for the design are given in Items 11 and 12 of the guidelines and assumptions.

The design maturity does not support a detailed assessment of these items. However, the control modes are:

- The deadband control ($\pm 5^{\circ}\text{C}$) will be a function of sensor locations (relative to the controlled point), the sensor accuracy, control type (on/off, proportional, etc.) and the response/accuracy of the electronics.
- The thermal stability (2°C) will require a tradeoff of the number and sizes of trim heaters, environmental changes, furnace mass and control type.
- The spatial gradients ($\pm 0.1^{\circ}\text{C}$) must be controlled by providing sufficient heat conduction for each cell.

3.4.2 POWER CONDITIONING/CONVERSION

The Orbiter voltage is subject to a number of variations of short and long term character. For instance, the types of variations encountered at the Cargo Bay buses is shown in Table 3-6*. It is expected that the facility electronic items will require that such variations be controlled in order to obtain adequate performance for sensors, heaters, signal conditioning and reference functions.

*These data are used as generic characteristics for conceptual design purposes.

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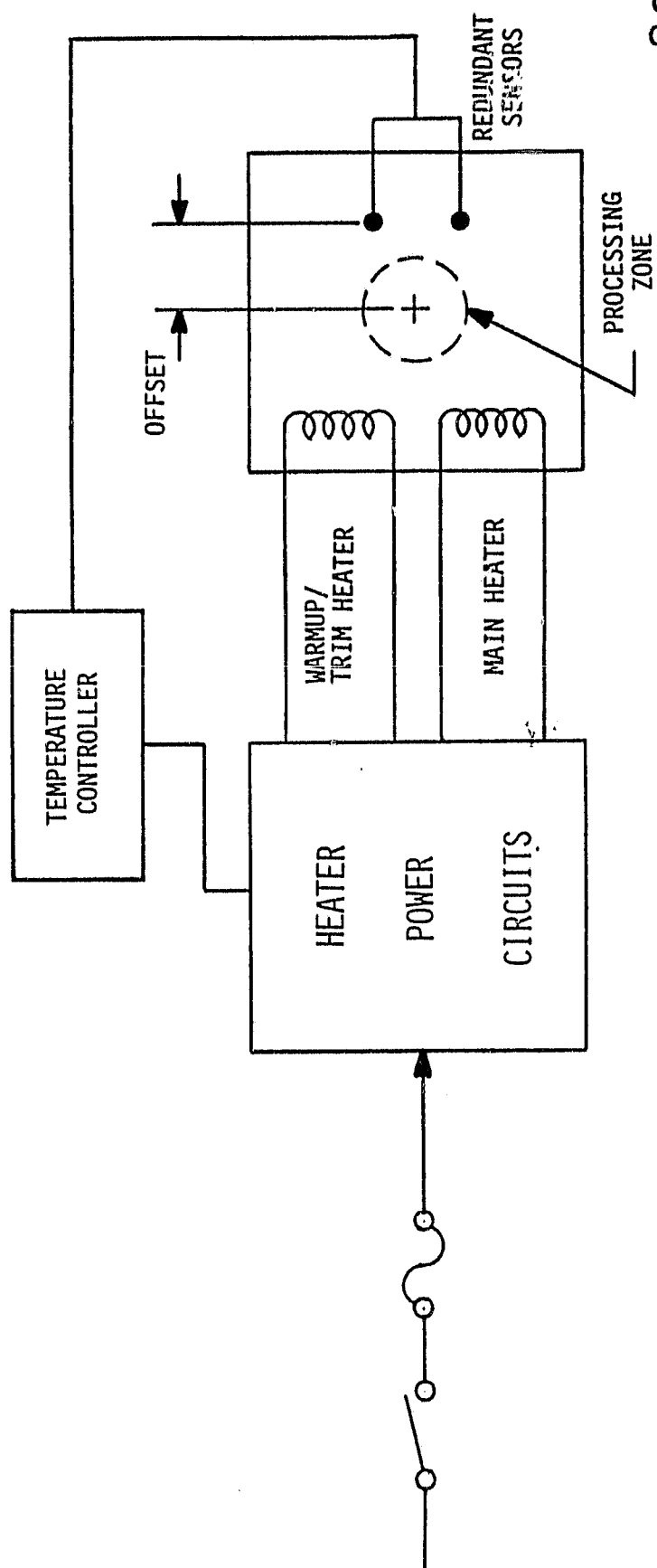


FIGURE 3-9. TEMPERATURE CONTROL CONCEPT

TABLE 3-6. TYPICAL ORBITER VOLTAGE QUALITY*

- STANDARD

- 28 V \pm 4 V

- QUALITY

IN-FLIGHT DC POWER BUS RIPPLE AT THE INTERFACE SHALL NOT EXCEED:

- 0.9 VOLTS PEAK-TO-PEAK NARROWBAND (30 Hz TO 7 kHz) FALLING 10 dB PER DECADE AT 0.28 VOLTS PEAK-TO-PEAK AT 70 kHz, THEREAFTER REMAINING CONSTANT TO 400 MHz.
- THE MOMENTARY COINCIDENCE OF 2 OR MORE SIGNALS AT ANY ONE FREQUENCY SHALL NOT EXCEED THE ENVELOPE DEFINED AS 1.6 VOLTS PEAK-TO-PEAK (30 Hz TO 7 kHz), FALLING 10 dB PER DECADE TO 0.5 VOLTS PEAK-TO-PEAK AT 70 kHz, THEREAFTER REMAINING CONSTANT TO 400 MHz.
- UNDER THE CONDITIONS OF A PASSIVE PAYLOAD (RESISTIVE SIMULATION OF LOAD), THE RIPPLE ON THE POWER SUPPLIED SHALL NOT BE GREATER THAN 0.8 VOLTS PEAK-TO-PEAK BROADBAND (DC TO 50 MHz); NO DISCRETE FREQUENCY SHALL EXCEED 0.4 VOLTS PEAK-TO-PEAK. THIS CONDITION SHALL APPLY AT THE MID-BODY POWER INTERFACE ONLY.

*Paragraph 7.2.2, "Space Shuttle System Payload Accommodations," Ref. 6.

Also, the electrical characteristics of the processing cells is such that the processing power must be converted in voltage/current to obtain the required levels. A significant problem occurs if it is necessary to convert the current levels to higher values at low voltages since such conversion can be very inefficient.

The conceptual design of the necessary electronics has not been accomplished. For estimating purposes, the following efficiencies have been assumed:

- Downwards conversion of bus voltage with upwards conversion of bus current ~60% efficiency.
- Downwards conversion of bus voltage and current ~80% efficiency.

The latter case is typical of off-the-shelf converter applications for which efficiencies range from 60% to as much as 90%. The 80% value is assumed since a converter selected or designed for the specific application will be used with optimum efficiency as a selection/design parameter.

The downwards conversion of voltage and upwards conversion of current is relatively inefficient for cases such as the subject process because of the low voltages involved: The voltage drop across converter components can approach the load voltage levels which results in significant internal power dissipation and low overall efficiency.

If v_I is the voltage drop across the converter and v_L is that of the load, the efficiency (η) is roughly

$$\eta = \frac{v_L}{v_I + v_L}$$

For the range of values given in Section 2.5 for the voltage drop across the cells and a 1.0 V drop across the converter, the efficiency computed in this fashion ranges from 47 to 72%. An approximate value of 60% has been assumed.

3.4.3 Shutter Driver

The gas type shutter driver envisioned for the system is shown schematically in Figure 3-10.

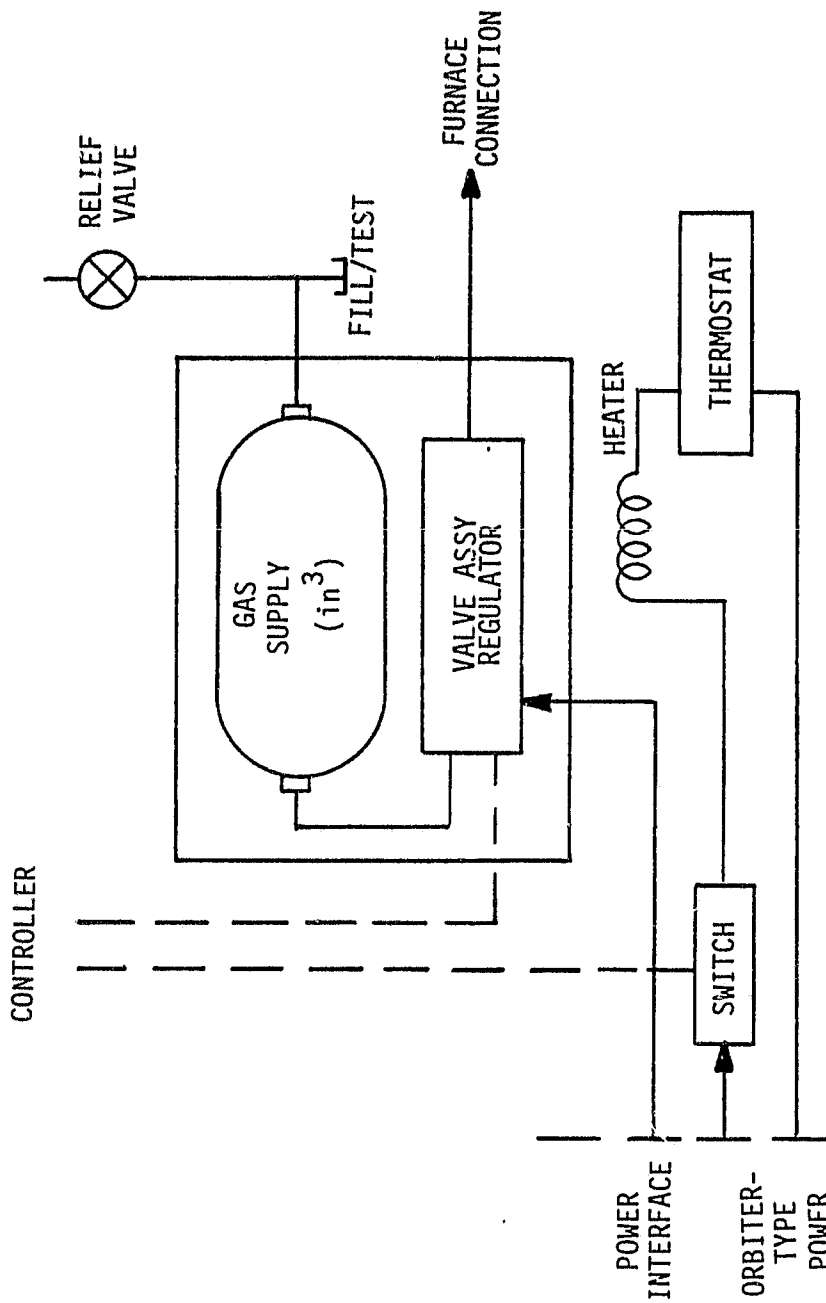


FIGURE 3-10. GAS HANDLER (SHUTTER DRIVER)

3.5 FACILITY PERFORMANCE (ANALYTICAL RESULTS)

Analyses have been performed for the furnace heat loss, touch temperatures of the crew shield, power distribution losses within the furnace, and the mass/volume requirements for the facility elements.

3.5.1 Heat Loss

The heat loss for the insulation profile of Table 3-4 has been evaluated using a three-dimensional thermal model. The results of the analyses are as follows:

Ambient Temperature (°F)	Furnace Heat Loss (W)
70	202.2
80	201.7
90	201.2

This loss is that through the insulation and does not include the 100 W calculated (by hand) for penetration and supports. The total loss is approximately 300 W. This loss is relatively independent of the ambient temperature range because the overall driving potential (greater than 830 °C) is much larger than the difference in the ambient temperatures.

3.5.2 Touch Temperatures

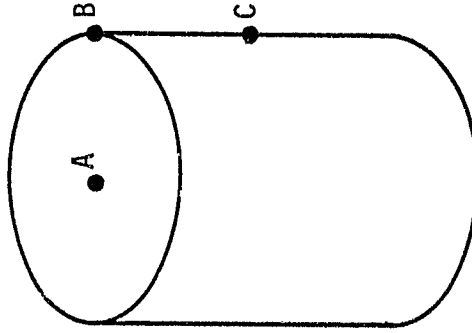
The initial assessment of the temperature of the Crew Shield is given in Table 3-7. The touch temperature is seen to be exceeded for all but the 70°F case and it is exceeded at one point even for that case.

As noted in the table, these temperatures are for a uniform thermal environment. A problem is that within a double locker space the confined (rear) region would get hot, creating a non-uniform environment and higher touch temperatures.

These results are preliminary and it is felt that the temperature can be reduced to acceptable levels in a uniform thermal environment by further design. However, it is not expected that the lower temperature can be obtained within the partially confined envelope of a double locker space. The furnace must protrude significantly into the cabin space.

TABLE 3-7. PRELIMINARY CREW SHIELD TEMPERATURES (°F)

AMBIENT TEMPERATURE	LOCATION		
	TOP CENTER (A)	CORNER (B)	SIDE CENTER (C)
70	101	95	119
80	110	103	127
90	119	112	135



NOTES:

1. MAXIMUM ALLOWABLE TEMPERATURE = 115° F
2. UNIFORM THERMAL ENVIRONMENT

3.5.3 Intra-Furnace Distribution Losses

Hand calculations indicate that the graphite/Ga water approach to process power distribution has a power loss of approximately 13% of the process power required for three cells. It is assumed that the Ga wafer reduces the joint losses to insignificant levels.

3.5.4 Mass Estimate

The mass estimate for the facility is given in Table 3-8. The Monodisperse Latex Reactor (MLR) data for electronics were employed with a 50% margin based on the MLR involving similar but simpler functions.

3.5.5 Volume Estimate

As noted in Section 3.2.7, the crew shield defines the volume of the furnace (18 in. diameter x 20 in. height). This volume is consistent with the available envelope of a double locker.

The size of the electronics has been estimated from the expectation that its cooling will dominate its packaging. The derating criteria of Figure 3-11 were used to estimate the necessary areas for surface cooling (free convection/radiation cooling under low-g) and for cold-plate cooling. The results of the estimates are given in Figure 3-12.

The assessment of these data are that cooling of the electronics will be marginal in a single locker envelope for surface cooling although only minimal cold plate area is required.

TABLE 3-8. FACILITY MASS ESTIMATES

FURNACE/SUPPORTS	- - - 67*
ELECTRONIC BOXES	- - - 60**
GAS HANDLER	- - - - - 10*
CABLING	- - - - - 6**

TOTAL 143 LBS

*ESTIMATED FOR TBE DESIGN

**MLR MASSES WITH 50% MARGIN

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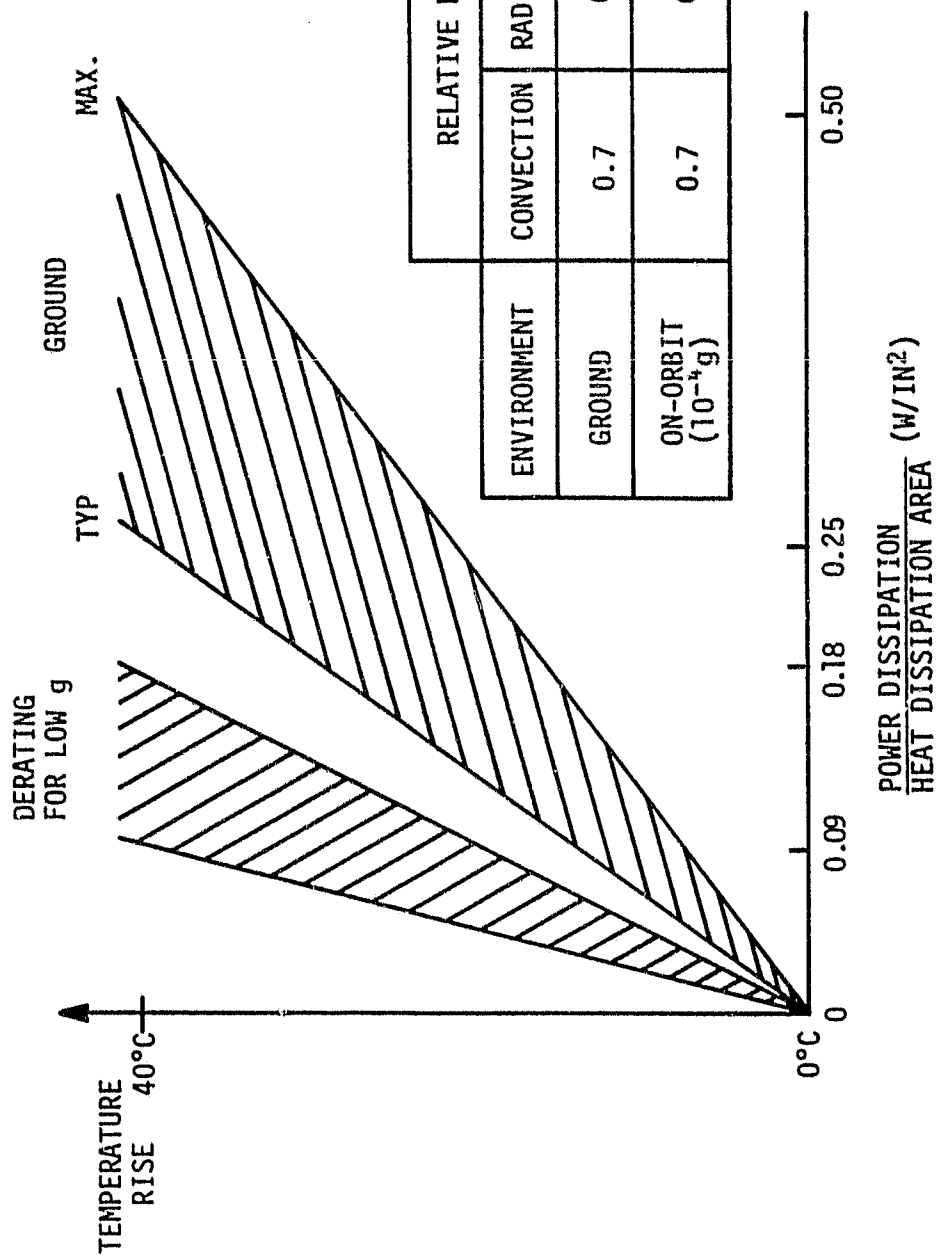
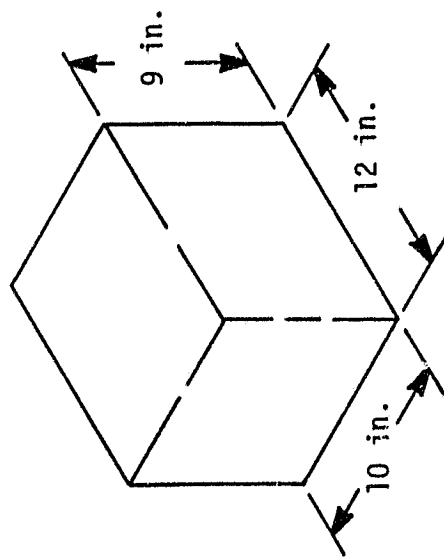


FIGURE 3-11. THERMAL DESIGN CRITERIA FOR ELECTRONIC BOXES

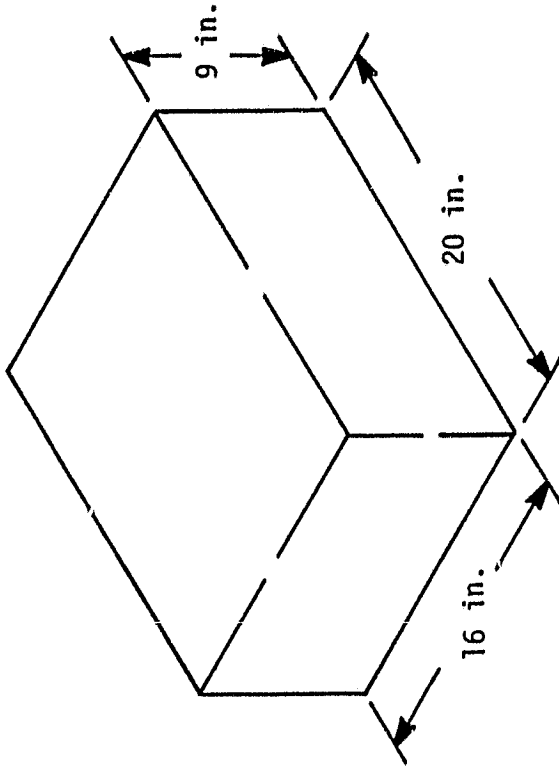
- MIDDECK (CONVECTION/RADIATION)



MIN.

DOES NOT INCLUDE GFE FOR MID-DECK

MAX.



- MEA (CONDUCTION TO COLD PLATE)

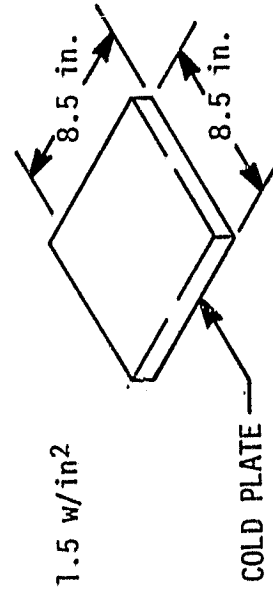


FIGURE 3-12. ELECTRONIC PACKAGING (THERMAL SIZING)

4. MIDDECK ACCOMMODATIONS ASSESSMENT

The basic furnace facility concept of Section 3 was configured for installation in the Orbiter Middeck and has been compared with Middeck capabilities. The Orbiter Middeck capabilities are described in Reference 3 and items pertinent to this assessment are discussed in the following paragraph.

4.1 MIDDECK ACCOMMODATIONS

A summary of Middeck capabilities is given in Table 4-1. These values are the standard accommodations available to all users. The number of power outlets or storage lockers available for a particular experiment is mission dependent.

Typical power provisions and cable routing is shown in Figures 4-1 and 4-2 respectively. Three 28VDC, 10 amp outlets and two 115VAC (400 Hz, 3-phase, 3 amp per phase) outlets are available. It is implied that the nominal power budget (and attendant heat rejection) for all outlets combined is 280 watts. It is unlikely that significant additional power (heat rejection) could be negotiated.

The location of potential Middeck stowage lockers are shown in Figure 4-3. The stowage lockers may be removed and replaced by single (Figure 4-4) and double (Figure 4-5) adapter plates. The available stowage volume extends about 20 inches from the adapter plates.

The maximum weight and center of gravity of experiment hardware mounted on the adapter plates is shown in Table 4-2.

The Middeck accommodations provide only the convective cooling of cabin air for heat dissipation.

No standard provisions are available for data handling.

4.2 ACCOMMODATIONS REQUIREMENTS

The basic accommodations requirements for the Middeck furnace and a separate electronic package are adequate storage and operating space; electrical power and sufficient energy; adequate heat dissipation for furnace cool down and acceptable touch temperatures; and data handling capability. The details of these requirements are examined in the following paragraphs.

TABLE 4-1. MIDDECK ACCOMMODATIONS

- POWER ~ 280 W
 - CURRENT ~ 10A (MAX.)
- } ONE POWER OUTLET
- DOUBLE LOCKER ENVELOPE (WxHxD) ~ 18.1 IN x 21.9 IN x 20.0 IN*
 - SINGLE LOCKER ENVELOPE (WxHxD) ~ 18.1 IN. x 10.7 IN x 20.0 IN*
 - COOLING ~ 280W (IMPLIED)
 - DOUBLE LOCKER ALLOWABLE MASS ~ 88 TO 138 LB (DEPENDING ON C.G.)
 - SINGLE LOCKER ALLOWABLE MASS ~ 44 TO 69 LB (DEPENDING ON C.G.)
 - DATA ~ NO DATA PROVISIONS

*MEASURED FROM FACE OF ADAPTER PLATES

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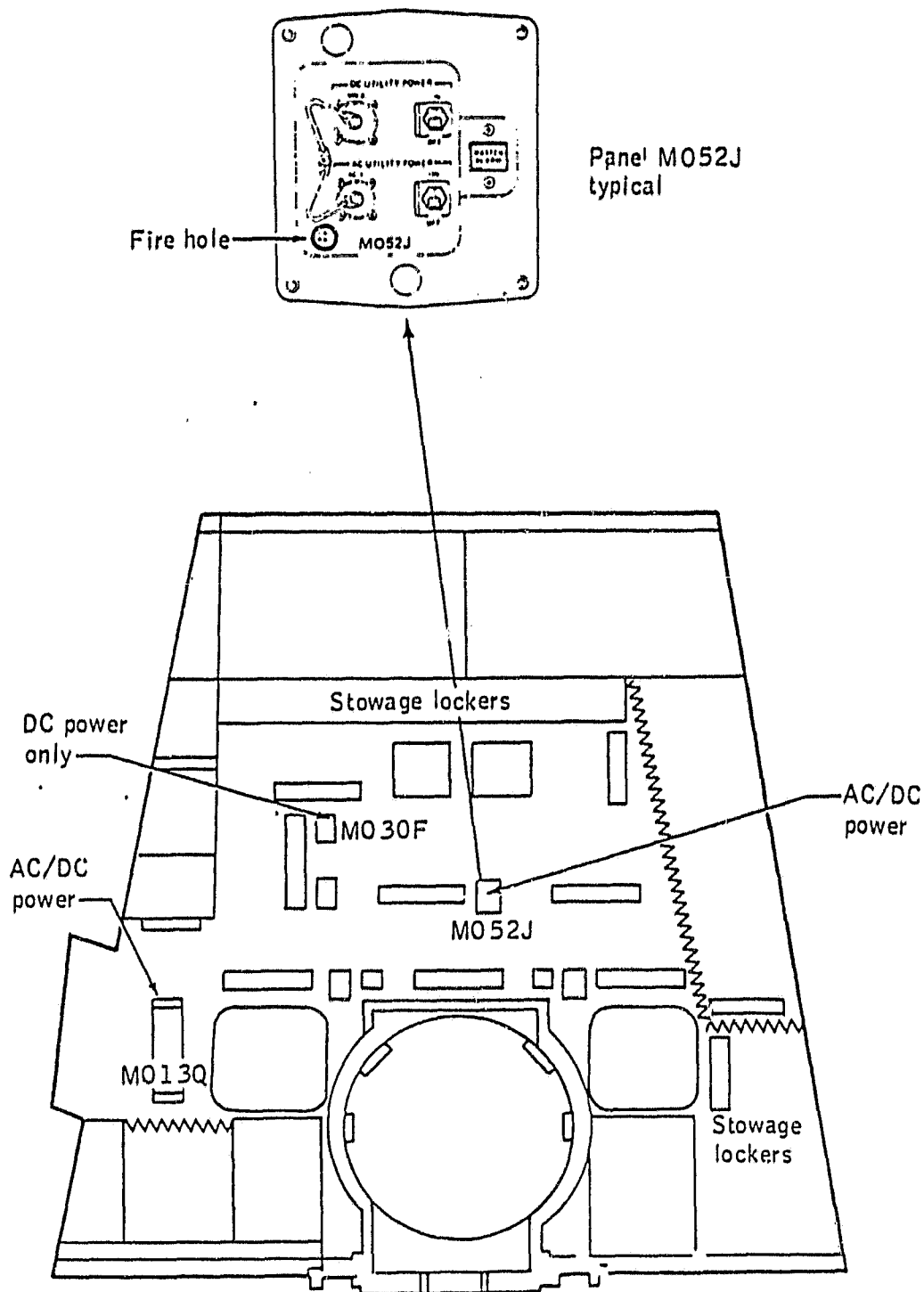


FIGURE 4-1 MIDDECK POWER PROVISIONS

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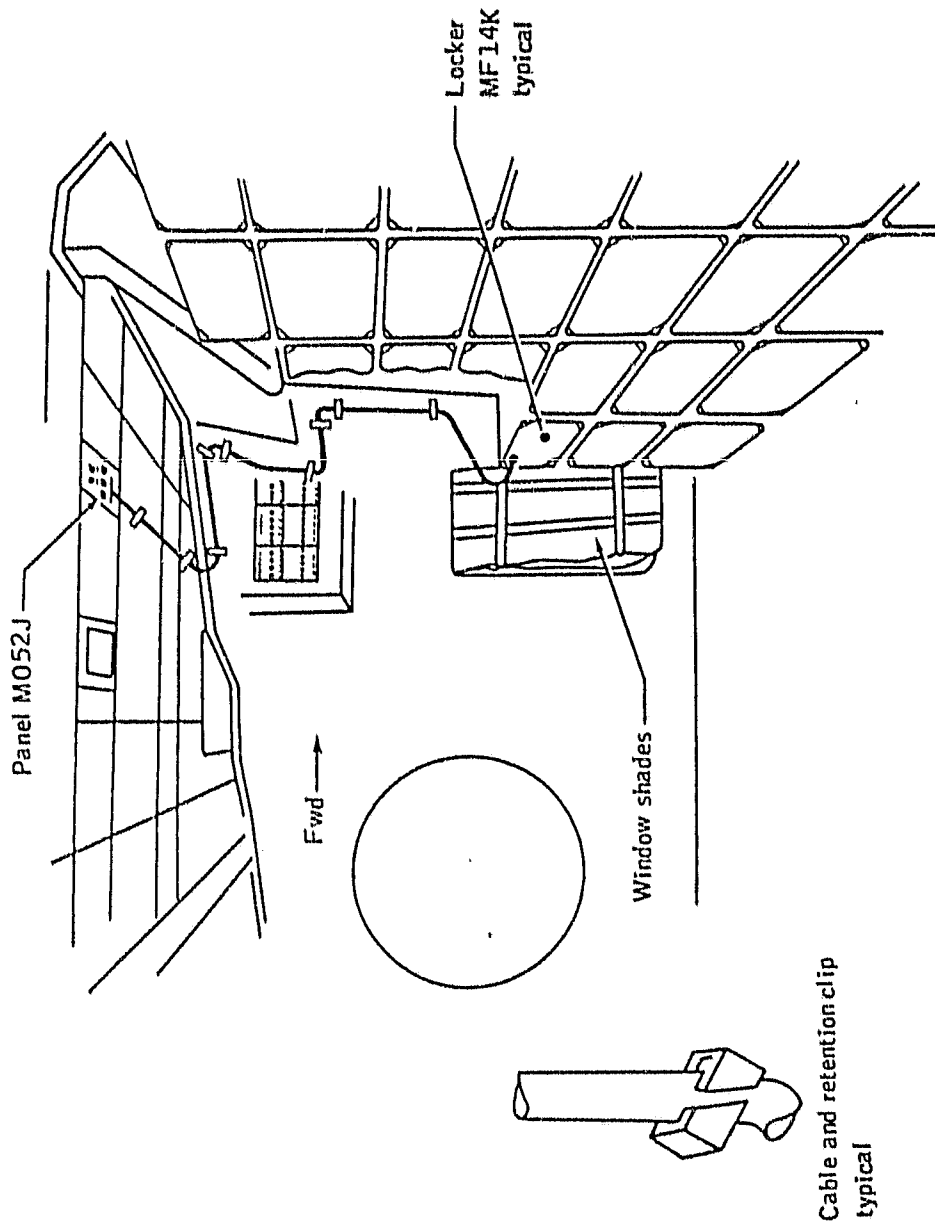


FIGURE 4-2 TYPICAL MIDDECK CABLE ROUTING

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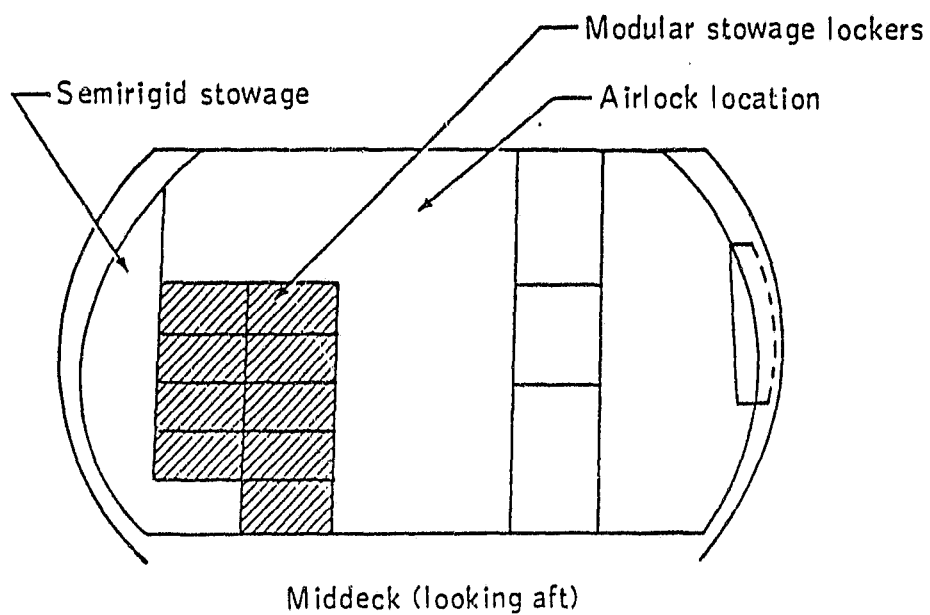
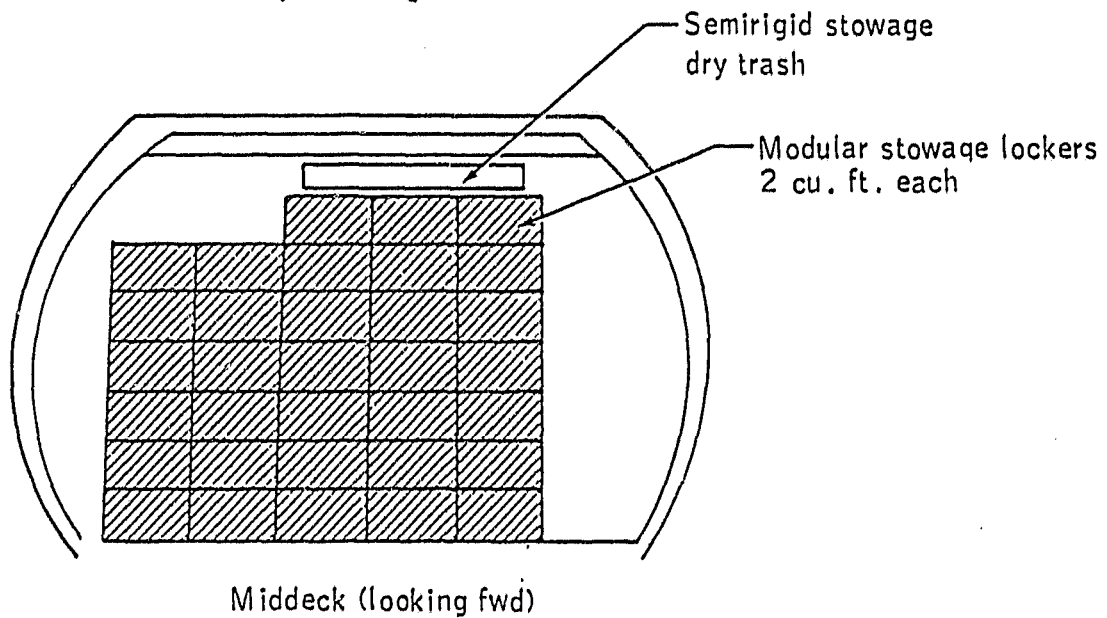


FIGURE 4-3 MIDDECK MODULAR STOWAGE LOCKER CONFIGURATION

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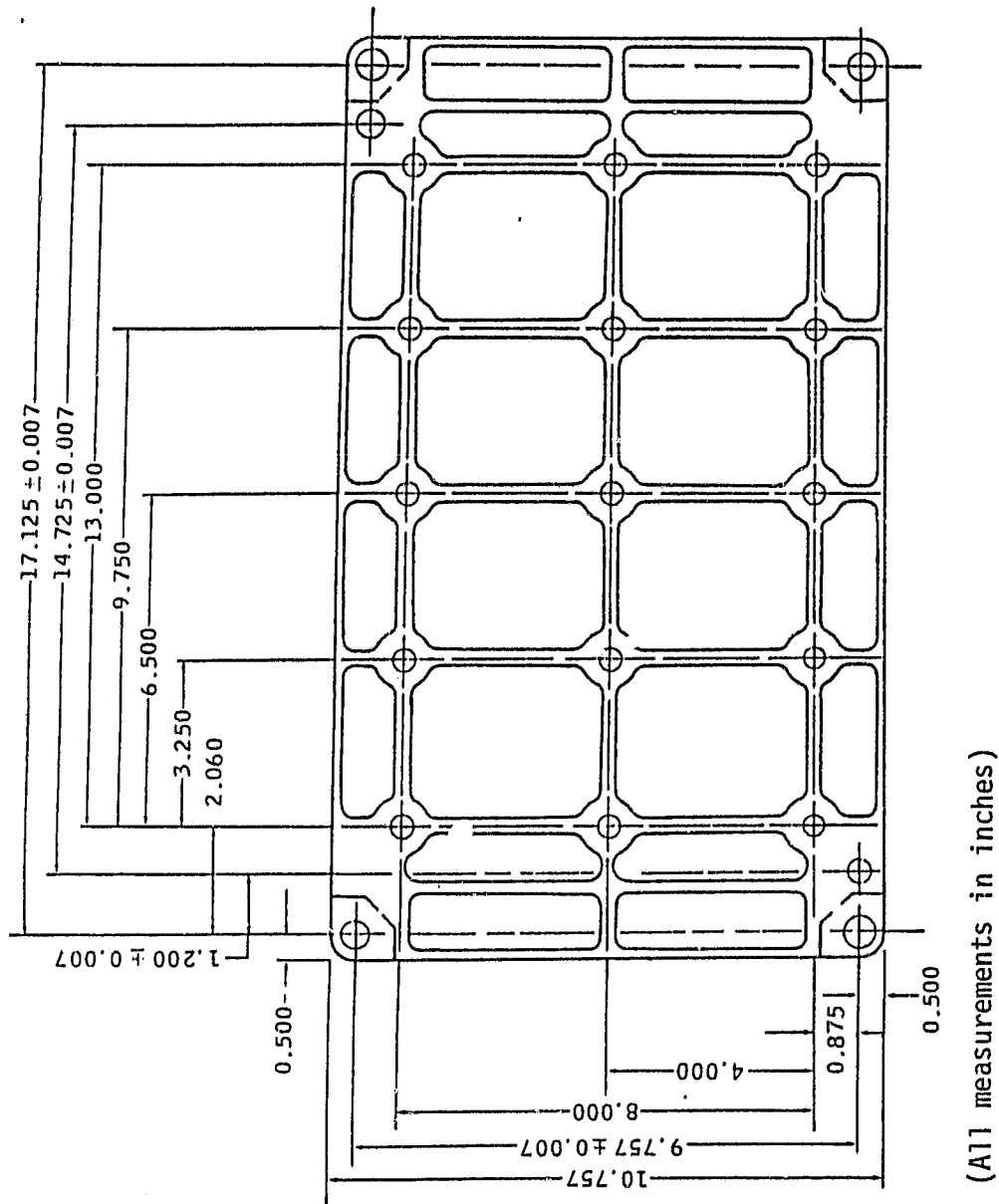
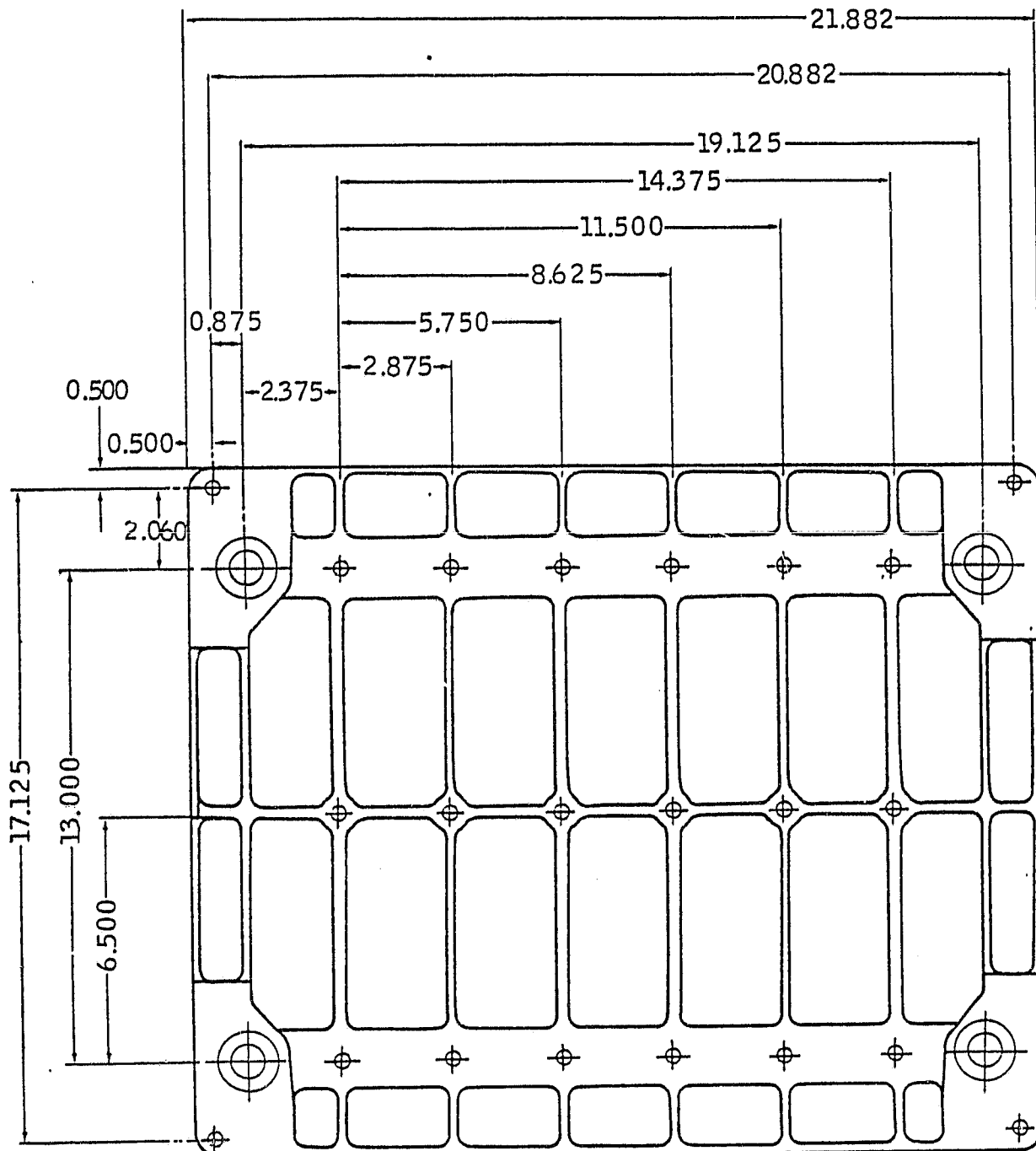


FIGURE 4-4 MIDDECK PAYLOAD ACCOMMODATION KIT SINGLE ADAPTER PLATE

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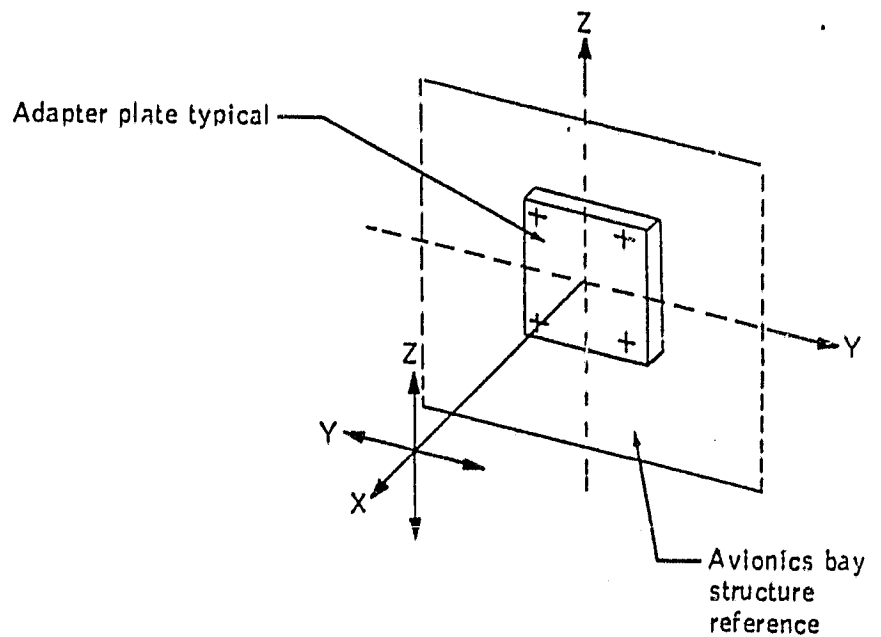


(All measurements in inches)

FIGURE 4-5 MIDDECK PAYLOAD ACCOMMODATION KIT DOUBLE ADAPTER PLATE

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TABLE 4-2. MAXIMUM EXPERIMENT WEIGHT AND CENTER OF GRAVITY



Center of plate	
CG (in) X	Wt. (lb)
14	51
13	55
12	59
11	65
10	69

, ± 3 inch Y	
CG (in) X	Wt. (lb)
14	37
13	40
12	44
11	43
10	52

± 3 inch Z	
CG (in) X	Wt. (lb)
14	31
13	34
12	37
11	40
10	44

4.2.1 CURRENT/POWER/ENERGY/TIME

The power estimates for the Middeck Facility are given in Table 4-3. Power ranges were selected to examine maximum/minimum expected values for different warmup times and varying process power due to cell resistivity changes. A nominal power requirement of about 500 watts is indicated unless a warm up time of less than about 20 hours is needed.

Total process time consists of warmup (Figure 4.6), processing (Table 2-3) and cool down (Table 4-4) components.

Time and energy estimates for the Middeck furnace/facility are given in Table 4-5 as a function of warmup time and process current density. These estimates are for 0.6 cm crystal growth and cooldown to 300°C. The region where the processing time is within the 96 hour guideline is indicated.

4.2.2 MASS/VOLUME/MOUNTING

The volume of the Middeck furnace is a cylinder 18 inches diameter by 21 inches length. The furnace envelope includes the basic furnace and a crew shield to lower touch temperatures. The volume requirements for Middeck electronics components is illustrated by Figure 3.12. The electronics package was sized on basic thermal criteria for electronic component cooling (power dissipation/heat dissipation area). Mass estimates are given in Table 4-6. No special mounting provisions are required except sufficient clearance for convective and radiative heat dissipation is necessary.

4.2.3 COOLING

Heat dissipation of 500 watts during processing and possibly 700 watts for warmup times of 10 hours are required for furnace and electronics combined (Table 4-3). The crew shield must be cooled to acceptable touch temperatures of 45°C.

4.2.4 DATA

The requirements for data for the R&D facility are undefined at this time in terms of number, types, ranges, sampling frequencies and accuracies. However, sufficient acceleration, temperature, electric current, discrete event occurrence and other data must be recorded to permit post-flight assessment of the facility, its operation and the quality of the crystals.

TABLE 4-3. MIDDECK FACILITY POWER ESTIMATE

	POWER RANGES (W)				
	STANDBY	WARMUP	EQUILIBRATE (15 min)	PROCESS	COOLDOWN
1. SENSOR CONDITIONING/DATA HANDLING	30	30	30	30	30
2. GAS HANDLING	0	0	5	0	0
3. PROCESS CONTROLLER	0	20	20	20	0
4. FACILITY CONTROLLER	15	15	15	15	15
5. TEMPERATURE CONTROLLER	0	30	30	30	0
6. FURNACE HEATERS	0	300/475	300	250/300	0
7. PROCESS POWER CONVERSION (60% EFFICIENCY)	0	0	0	3/33	0
8. GFE (RECORDER/ACCELEROMETER)	10	10	10	10	10
9. PROCESS POWER	0	0	0	5/50	0
10. DISTRIBUTION LOSSES (10%)*	6	41/58	41	41/44	6
11. FACILITY POWER CONDITIONING (90% EFFICIENCY)**	6	45/64	45	40/45	6
TOTALS	67	491/702	496	494/527	67

*EXCLUDES PROCESS LOSSES IN FURNACE

**EXCLUDES PROCESS POWER

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PRELIMINARY
BUDGET

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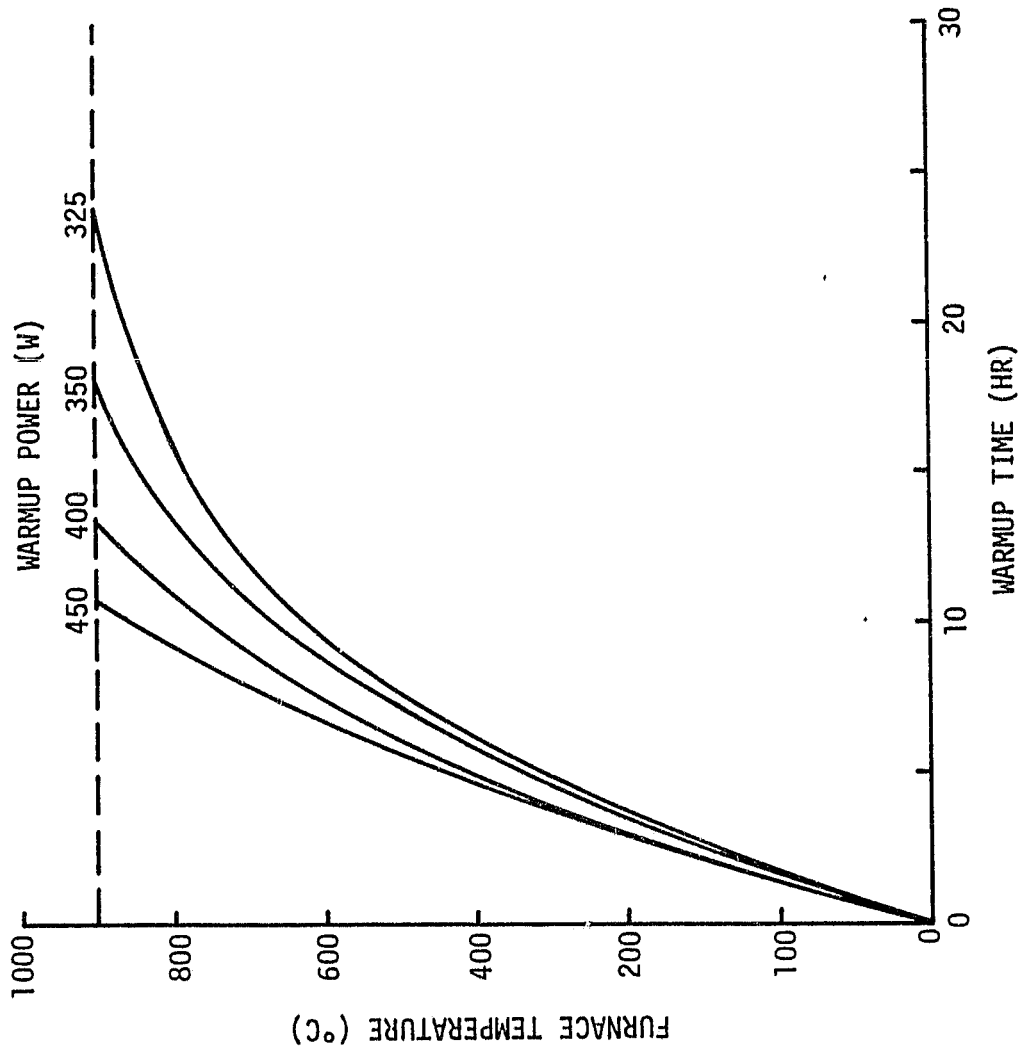


FIGURE 4-6. WARMUP TIME AS FUNCTION OF HEATING RATE
FOR MIDDECK FURNACE

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TABLE 4-4. COOLING TIME (HOURS)

FINAL TEMPERATURE (°C)	MIDDECK FURNACE (HR)
600	4.2
500	6.0
400	8.4
300	10.8

NOTE: 900°C INITIAL TEMPERATURE

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TABLE 4-5. MIDDECK PROCESS TIME (HR)/ENERGY (KWH)

CURRENT DENSITY (A/cm ²) WARMUP TIME (HR)	TIME					ENERGY				
	8	12	16	20	24	8	12	16	20	24
10	154 72.7	110 51.7	88 40.9	74 34.6	65 30.3	154 72.7	110 51.7	88 40.9	74 34.6	65 30.3
15	159 74.4	115 53.4	93 42.6	79 36.3	70 32.0	159 74.4	115 53.4	93 42.6	79 36.3	70 32.0
20	164 76.5	120 55.5	98 44.7	84 38.4	75 34.1	164 76.5	120 55.5	98 44.7	84 38.4	75 34.1
25	169 78.7	125 57.7	103 46.9	89 40.6	80 36.3	169 78.7	125 57.7	103 46.9	89 40.6	80 36.3
30	174 82.8	130 61.8	108 51.0	94 44.7	85 40.4	174 82.8	130 61.8	108 51.0	94 44.7	85 40.4

NOTES:

1. 0.6 CM GROWTH
2. COOL DOWN TO 300°C (11 HRS.)

TABLE 4-6. MASS ESTIMATES (MIDDECK)

FURNACE/SUPPORTS	- - -	67*
ELECTRONIC BOXES	- - -	60**
GAS HANDLER	- - - - -	10*
CABLING	- - - - -	6**

TOTAL 143 LBS

*ESTIMATED FOR TBE DESIGN

**MLR MASSES WITH 50% MARGIN

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The expectation is that the instrumentation, sensor conditioning, etc. for the process parameters will be part of the facility design and that acceleration measurement provisions and equipment for data recording will be GFE items.

It is not expected that experimental data will be required for any mission phase other than during the end-to-end processing cycle. Also, the need for real time, downlinked data is not expected because of the inability to correct or adjust the growth process.

4.3 ACCOMMODATIONS ASSESSMENT

The R&D furnace requirements exceed the capabilities of the Middeck facility. The Middeck Accommodations Summary (Table 4-7) shows insufficient or marginal capability in nearly all categories considered.

4.3.1 Current/Power/Energy/Time*

The 500 W nominal power requirement is significantly above the 280 W standard outlet capability. Process current density requirements would require boosting the amperage in an inefficient conversion process. The implied available energy is limited by the 10 amp allowable power drain which can only be increased by negotiations on a mission-by-mission basis.

4.3.2 Mass/Volume/Mounting

The furnace may be mounted in the double locker space without mass or physical interference problems. A single locker mounting for the electronics components appears adequate in dimension; however, the 60 pound electronics and 10 pound gas-handler mass is in excess of the allowable. This is judged as marginal due to the immaturity of the mass estimates.

4.3.3 Cooling

The heat dissipation requirements (paragraph 4.2.3) are significantly greater than the 280 W implied capability. If additional power were negotiated, an active thermal control subsystem would probably be required.

*These issues were discussed with Johnson Space Center.

TABLE 4-7. MIDDECK ACCOMMODATIONS SUMMARY

● CURRENT	} REQUIREMENTS EXCEED CAPABILITY FOR ONE STANDARD DC OUTLET. ADDITIONAL POWER NEGOTIABLE ON MISSION BASIS
● POWER	
● ENERGY	
● COOLING	REQUIREMENTS EXCEED CAPABILITY
● MASS	FURNACE ACCOMMODATED (DOUBLE LOCKER) ELECTRONICS MARGINAL (SINGLE LOCKER)
● ENVELOPE	MARGINAL FOR FURNACE AND ELECTRONICS
● CREW I/F	MINIMUM ACTIVITY
● DATA	NO PROVISIONS
● SAFETY	MARGINAL IN TOUCH TEMPERATURE OTHERWISE HAZARDS CAN BE CONTROLLED

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The crew shield touch temperature (Table 3-7) exceeds the allowable 45°C. Cooling of the furnace would be further compromised due to the semi-enclosed mounting between storage lockers. Cabin air circulation could be improved if a more open mounting location were available.

4.3.4 Data

No provisions are available in the Middeck. Scientific data sensing and recording are judged as a significant inadequacy.

5. MATERIALS EXPERIMENT ASSEMBLY (MEA) ACCOMMODATIONS ASSESSMENT

The furnace/facility concept of Section 3 has been adapted to the MEA and its requirements compared with MEA capabilities. The MEA capabilities are those of Reference 4 modified by the assumption that Orbiter power and thermal control will be used.

5.1 MEA ACCOMMODATIONS

A summary of the MEA capabilities is given in Table 5-1. These values reflect the standard self-contained MEA characteristics with the exception of the sources for the power and cooling which are assumed to be obtained from the Orbiter.

The power level indicated is the standard quarter-section allocation of the Orbiter defined in Reference 6. This standard power level corresponds to nominal voltages and currents of 28 V and 62.5 A, respectively. Since the MEA wire sizes are designed for up to 105 A input to the conditioning/distribution circuits, the MEA can accommodate the Orbiter standard quarter-section. The MEA will consume some 200 W or so of this power.

Preliminary assessments of the MEA using Orbiter cooling, such as that given in Reference 7, have been that the MEA cooling loop will be limited to less than the full quarter section cooling capability. This is a conservative assessment and it is possible for the cooling capability to exceed the 500 W.

The basic MEA-A layout is illustrated in Figure 5-1. For MEA-B, the batteries and radiator will be removed and the thermal and electrical control equipment redistributed in the control section. Typically, experiments using MEA are designed to fit within Experiment Assembly Containers (EACs) such as those shown in Figure 5-2 for the first MEA. Two types of EACs are illustrated. The principal difference in the two configurations is the height of the mounting tabs above the base plane.

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TABLE 5-1. MEA ACCOMMODATIONS SUMMARY

● POWER	1750 W (QUARTER SECTION ALLOCATION)
● CURRENT LIMITS	~105 AMP @ 28 V
● TWO COMPARTMENT ENVELOPE (W x H x D) . . .	~40 x 40 x 20 INCHES
● SINGLE COMPARTMENT ENVELOPE (W x H x D) . .	~20 x 40 x 20 INCHES
● TYPICAL EAC ENVELOPE	~17 IN. DIA. x 37 IN. HIGH
● COOLING	500 AVG, 1000 PEAK
● TWO COMPARTMENT ALLOWABLE MASS	265 LB
● SINGLE COMPARTMENT ALLOWABLE MASS	132.5 LB
● DATA RECORDING	DEDICATED RECORDER 4 kbps 80 Mb STORAGE CAPACITY

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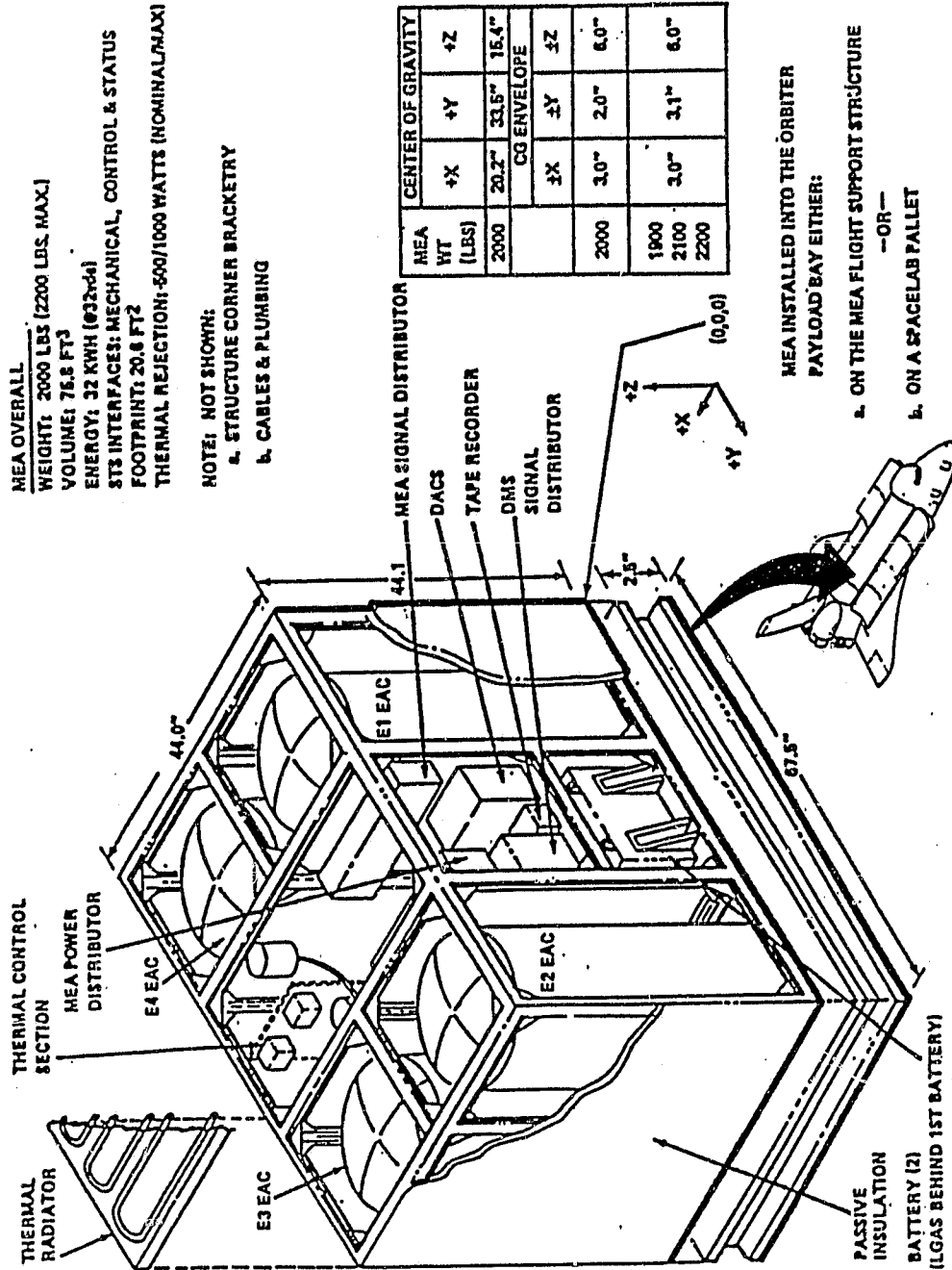


FIGURE 5-1. MEA LAYOUT

[illegible]

The MEA through its Data Management Subsystem (DMS) provides the services shown in Figure 5-3. The DMS functions include control, data storage and software provisions to augment experimental systems.

5.2 ACCOMMODATIONS REQUIREMENTS

The accommodations requirements for the MEA-based concept are essentially those for the Middeck-based concept with the following adjustments:

1. For the MEA it is assumed that all of the insulation for the furnace is passively evacuated.
2. The size of the furnace envelope is adjusted downwards to the MEA Experiment Assembly Container (EAC) envelope.
3. The electronics for the facility is assumed to be cold-plated and hermetically-sealed for the MEA application.
4. No touch temperature control is imposed on the furnace.

Additionally, the following guidelines were employed in the repackaging of the facility for the MEA.

1. Use of a single EAC envelope
2. The EAC mounting baseplate will be used but not the EAC container.

5.2.1 Current/Power/Energy/Time

The electrical power estimates for the facility are given in Table 5-2. These estimates differ from the Middeck values in the bulk heat leak, addition of an environmental heater, and in the assumption that direct Orbiter power is used. The processing power level is seen to be some 350 to 400 W which is 150 to 175 W less than for the Middeck. The primary difference is in the 200 W furnace heater power for the MEA furnace compared to the 300 W for the Middeck.

The processing time consists of warmup (Figure 5-4), processing (Table 2-3) and cooldown components (Table 5-3). The warmup time for the MEA furnace is less than for the Middeck because of the lower heat loss. The cooldown time for the MEA furnace is longer because of the improved insulation performance.

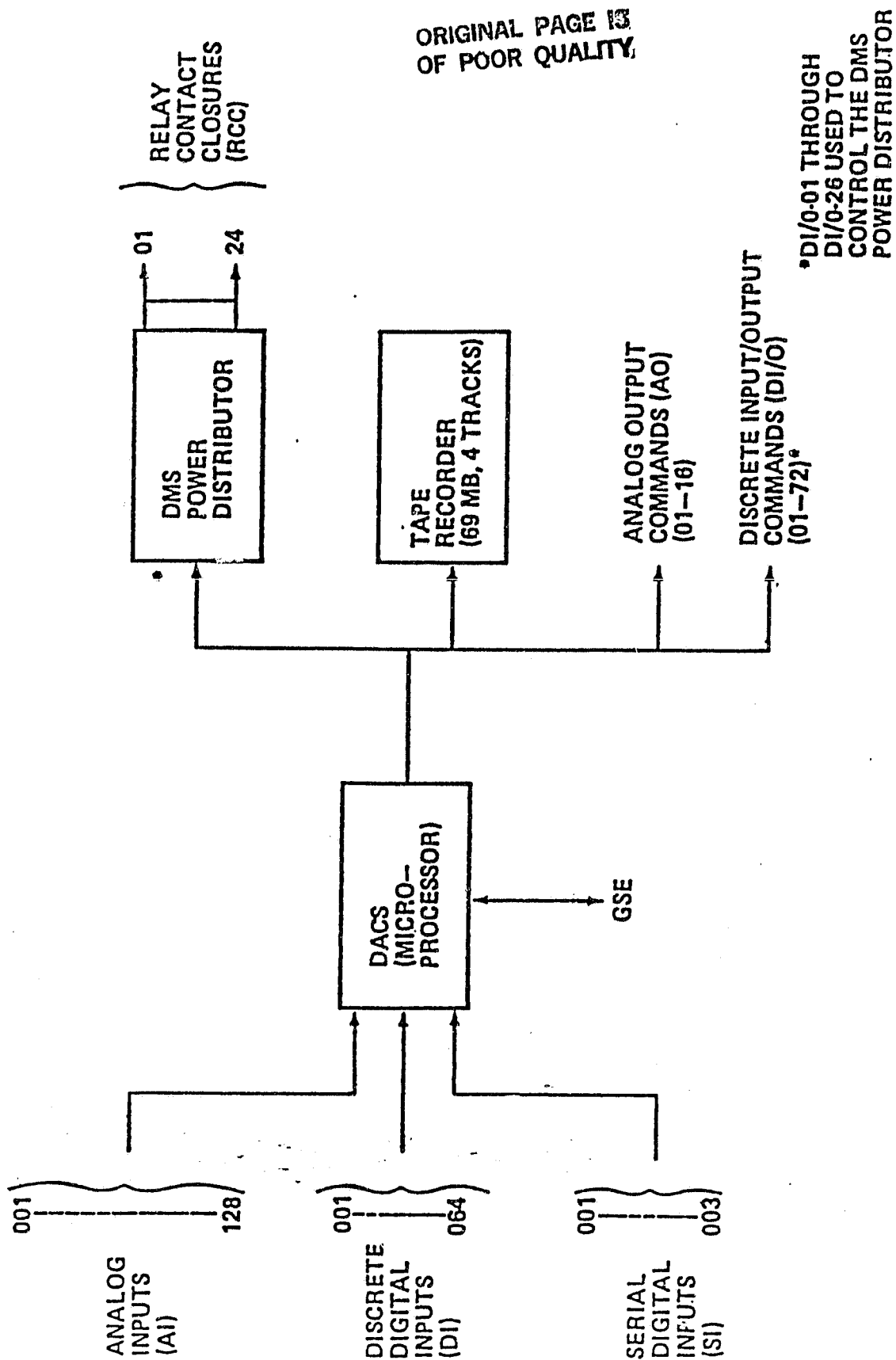


FIGURE 5-3. MEA DMS CAPABILITY

TABLE 5-2. MEA FACILITY POWER ESTIMATE

	POWER RANGES (W)				
	STANDBY	WARMUP	EQUILIBRATE (15 MIN)	PROCESS	COOLDOWN
1. SENSOR CONDITIONING/DATA HANDLING	30	30	30	30	30
2. GAS HANDLER	0	0	5	0	0
3. PROCESS CONTROLLER	0	20	20	20	0
4. FACILITY CONTROLLER	15	15	15	15	15
5. TEMPERATURE CONTROLLER	0	30	30	30	0
6. FURNACE HEATERS	0	200/300	200	150/200	0
7. PROCESS POWER	0	0	0	5/50	0
8. ENVIRONMENTAL HEATERS	0/30	0/30	0/30	0/30	0
9. DISTRIBUTION LOSSES (10%)	5/8	30/43	30/33	30/33	5
10. FACILITY POWER CONDITIONING (INCLUDING PROCESS @ 80% EFFICIENCY)	5/8	33/46	33/36	33/36	5
TOTALS	55/91	358/514	363/399	358/399	55

PRELIMINARY
BUDGET

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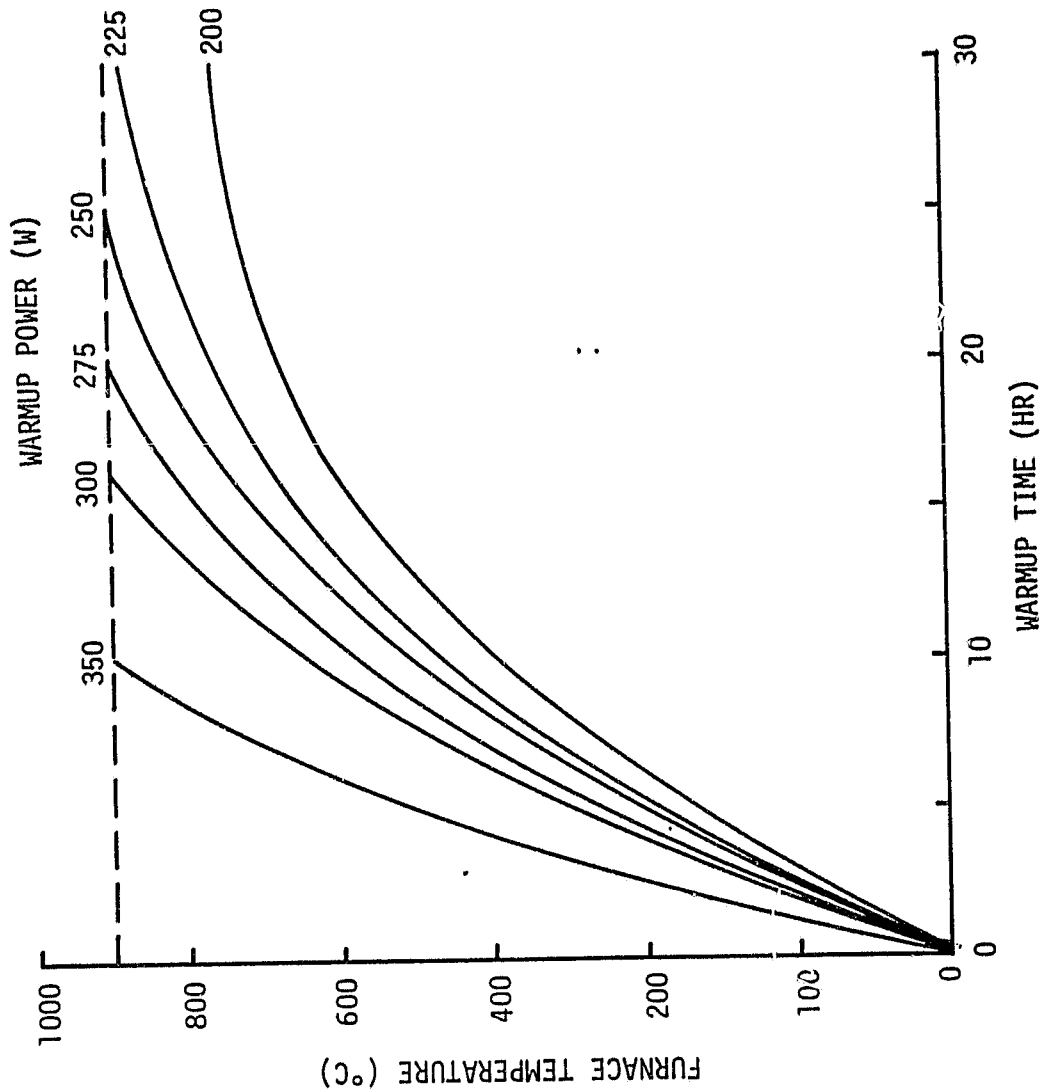


FIGURE 5-4. WARMUP TIME FOR MEA FURNACE

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TABLE 5-3. COOLING TIME (HOURS)
(900°C INITIAL TEMPERATURE)

FINAL TEMPERATURE (°C)	MEA FURNACE (HR)
600	6.1
500	8.8
400	12.2
300	16.6

The time and energy cases for the MEA furnace are illustrated in Table 5-4 as a function of warmup time and process current density. The region in which the processing time is within the 96 hour guideline is indicated.

5.2.2 Mass/Volume/Mounting

Sketches of the facility as packaged for the MEA are shown in Figures 5-5 and 5-6. The furnace/insulation occupy the upper portion of the EAC volume. As in Section 3, an end-mounted/conical support type structural attachment is used for the furnace. In this case, the furnace support is to a primary flange which is attached to a lower, open-frame structure which, in turn, is attached to the EAC baseplate. The electronics is mounted to the underside of the primary flange. Side-mounted cold plates are used to permit greater access to the electronics from the furnace and EAC baseplate for inter-connections.

In this packaging concept, the furnace employs a double containment as for the Middeck design, but the outer containment is reduced in size to permit greater use of evacuated insulation. The dimensions of the overall insulation envelope are also reduced from the 18 in. (dia.) x 21 in. (height) of the Middeck design to a 17 in. dia. x 20 in. (height) consistent with the EAC envelope.

The greater amount of passively evacuated insulation reduces the bulk heat leak from 200 W to 100 W. Assuming similar penetration losses as for the Middeck design yields a net heat leak of 200 W (two-thirds of the net Middeck loss).

The packaging concepts of Figures 5-5 and 5-6 require cold plate type cooling of the electronics (approximately 100 W cooling load) in order to achieve a sufficiently compact volume to fit within the allowable space. Ample volume and surface areas are available using typical rules of thumb (3 W/in^3 and 1.5 W/in^2 for acceptable volumetric and cold plate surface loadings, respectively). The available envelope is approximately 9 in. x 14 in. x 14 in.

The mass estimate for the facility is assumed to be equal to that for the Middeck (143 lb).

TABLE 5-4. MEA PROCESS TIME (HR)/ENERGY (KWH)

CURRENT DENSITY (A/cm ²) WARMUP TIME (HR)	TIME					ENERGY				
	8	12	16	20	24	8	12	16	20	24
10	160 53.2	116 38.2	94 25.6	80 26.1	71 23.1	160 53.2	116 38.2	94 25.6	80 26.1	71 23.1
15	165 54.7	121 39.7	99 32.1	85 27.6	76 24.6	165 54.7	121 39.7	99 32.1	85 27.6	76 24.6
20	170 56.2	126 41.2	104 33.6	90 29.1	81 26.1	170 56.2	126 41.2	104 33.6	90 29.1	81 26.1
25	175 57.6	131 42.6	109 35.0	95 30.5	86 27.5	175 57.6	131 42.6	109 35.0	95 30.5	86 27.5
30	180 59.3	136 44.3	114 36.7	100 32.2	91 29.2	180 59.3	136 44.3	114 36.7	100 32.2	91 29.2
						>96 HR				
						<96 HR				

NOTES:

1. 0.6 CM GROWTH
2. COOL DOWN TO 300°C (17 HRS.)

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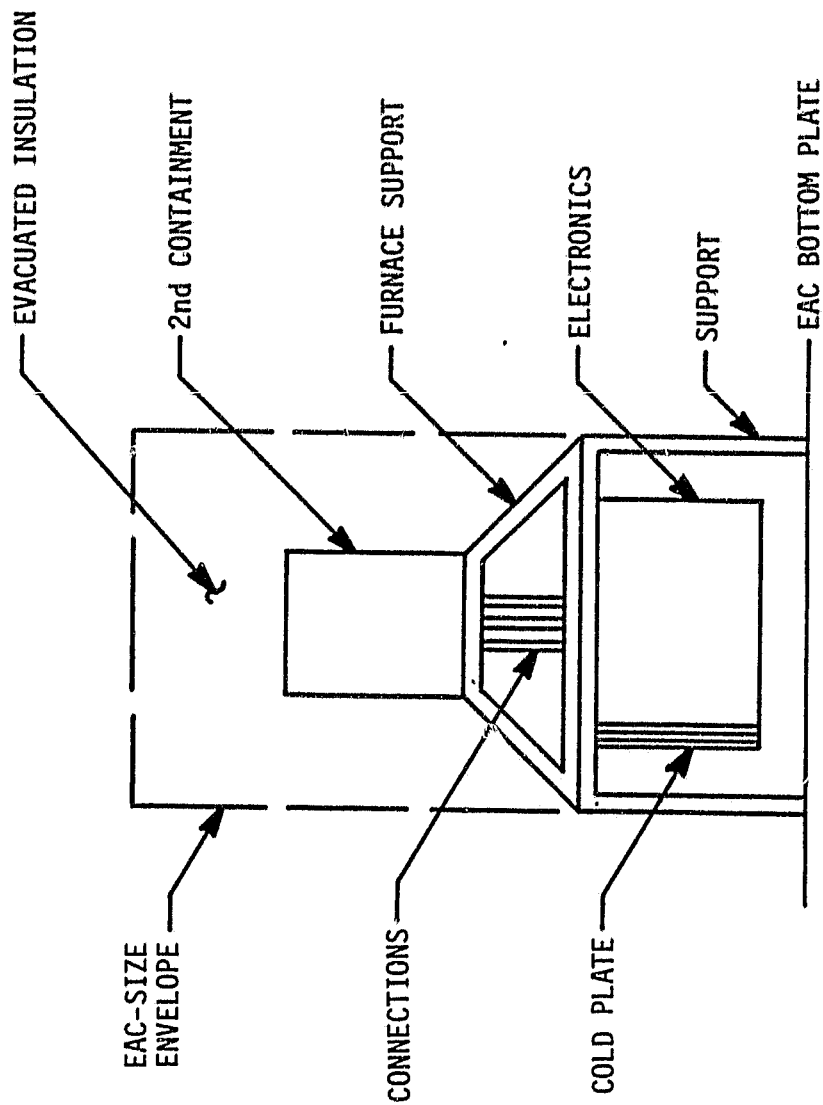


FIGURE 5-5. MEA SINGLE COMPARTMENT FACILITY LAYOUT

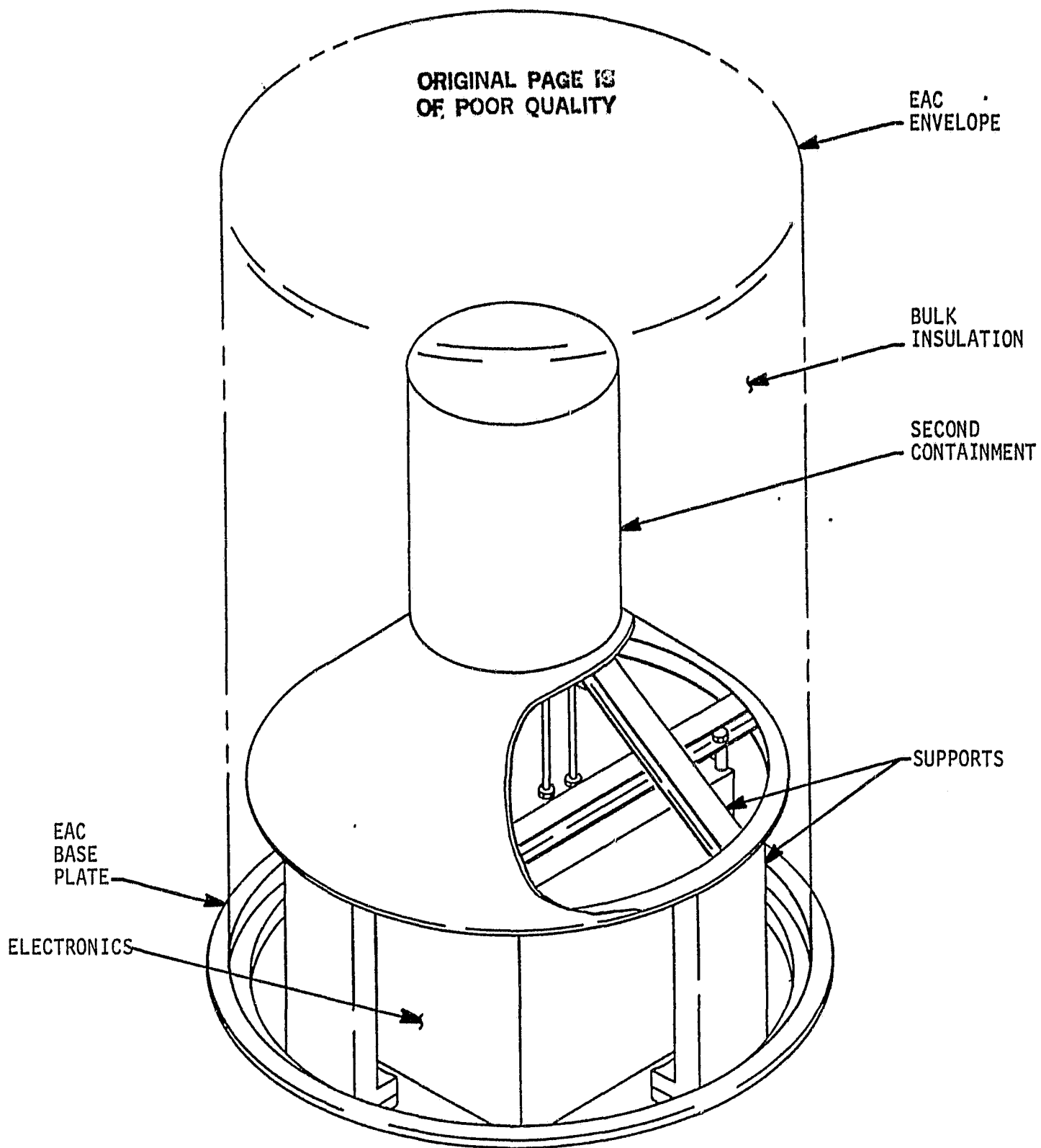


FIGURE 5-6. MEA FURNACE PACKING SKETCH

5.2.3 Cooling

Two modes of cooling are required for the MEA furnace/facility, the direct cooling of the electronics by cold plates (100 W) and the passive dissipation of furnace heat loss, distribution losses, etc. to surrounding MEA surfaces and then by conduction and radiation to environmental sinks. This approach may require additional insulation panels between the compartment used and adjacent compartments.

The cold plate size is relatively small as shown in Figure 3-12.

5.3 ACCOMMODATIONS ASSESSMENT

Overall, the MEA is judged to provide adequate accommodations capabilities for the R&D facility (Table 5-5).

5.3.1 Mass/Volume

There is judged to be adequate volume in a single experiment compartment for the R&D facility. The present mass estimate of 143 lb is within the 165 lb limit for a single experiment compartment (base mounting).

5.3.2 Power/Energy/Time

The projected power levels for the facility (less than 514 W) are well within the 1750 W capability of the MEA using Orbiter electrical services. However, the energy requirements (some 20 to 30 kWh) are a large fraction of the 50 kWh available for all experiments for the Orbiter with three fuel cells (the standard quarter-section allocation is 12.5 kWh). Therefore, manifesting constraints will probably have to be imposed if the facility is flown with the three fuel cell configurations. The addition of the fourth cell to the Orbiter adds 840 kWh and would negate any energy concerns.

The current levels of the MEA are not directly applicable to the R&D facility because of the small voltage drop across the cells (see Section 2.5). However, the conversion problem is simpler than for the Middeck because of the higher voltages/current levels available.

TABLE 5-5. MEA ACCOMMODATIONS SUMMARY

● MASS	ADEQUATE
● CURRENT	ADEQUATE
● POWER	ADEQUATE
● ENERGY	ADEQUATE
● COOLING	ADEQUATE
● ENVELOPE	ADEQUATE
● CREW I/F	MINIMUM ACTIVITY
● DATA	ADEQUATE
● SAFETY	HAZARDS CAN BE CONTROLLED

5.3.3 Cooling

The MEA cooling loop capability of 500 W is adequate for the R&D facility since only a portion (some 100 W) of its electrical load requires cold plate type cooling. The remaining heat (up to 300 W) is to be dissipated passively. This approach will require careful design of the facility and probably thermal isolation of its experiment compartment.

The cold plate size required can be accommodated.

5.3.4 Data

The MEA is very flexible in its data handling capabilities and has sufficient data channels and recording capacity for process type measurements (temperature, currents, etc.). Although data and recording requirements are unspecified, it is felt all reasonable requirements can be accommodated.

6. GET AWAY SPECIAL (GAS) CAN ACCOMMODATIONS ASSESSMENT

The process and experiment/payload requirements were re-analyzed in terms of a self-contained experimental facility using one or more GAS cans. The GAS can accommodations, derived from the Experimenters Handbook (Reference 5), were then assessed against the furnace facility requirements.

6.1 GAS CAN ACCOMMODATIONS

The "Get Away Special (GAS), Small Self Contained Payloads, Experimenters Handbook," October 1979, was used to derive the GAS Can Accommodations Capabilities.

The GAS Can, Figure 6-1, is an aluminum cylinder with an internal experiment envelope - 19.75 in. diameter x 28.25 in. high, for a net volume of 5 cubic feet and with an allowable mass of 200 pounds. There are available three (3) control circuits, one of which must be dedicated to removing all power from the payload. There are no provisions for power or data handling. The GAS Can is thermally isolated from the Orbiter with heat rejection limited to radiation through the top (experiment mounting) plate. The heat rejection capability is orbital attitude dependent as shown in Figures 6-2 and 6-3. An orientation between moderately cold and earth viewing was assumed. This would equate to a heat rejection capability of ~100 watts ($35 \text{ watts/ft}^2 \times 2.8 \text{ ft}^2 = 100 \text{ watts}$).

The GAS Can accommodations are summarized in Table 6-1.

6.2 ACCOMMODATIONS REQUIREMENTS

The accommodations requirements for the GAS concept are essentially those for the MEA concept with the addition of batteries to provide power. For the study, it was assumed that adequate Lithium type batteries (see Figure 6-4) could be procured/developed that would satisfy requirements of current, power, energy, weight and volume (one GAS Can). The GAS Can Accommodations Requirements are shown in Table 6-2.

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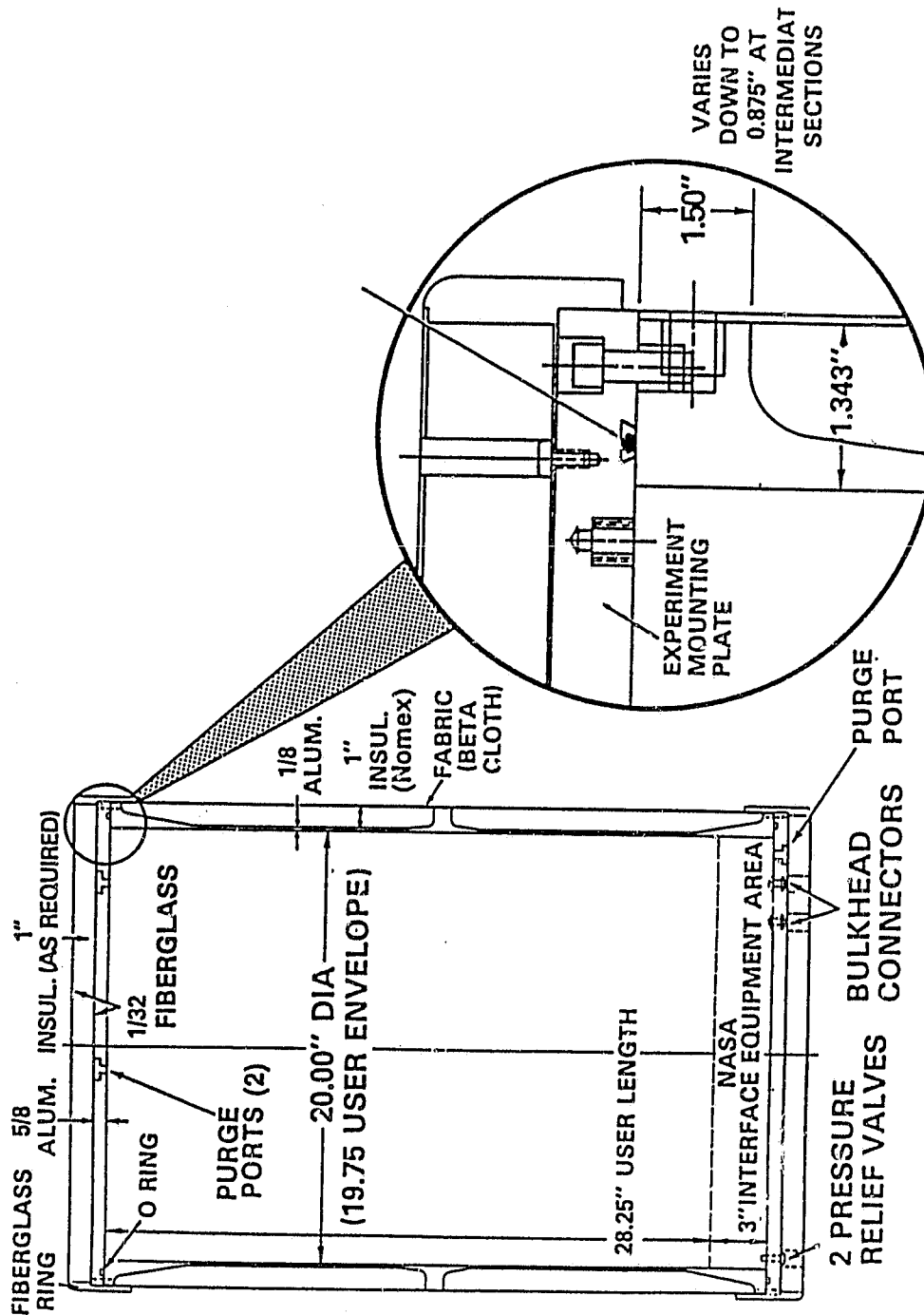


FIGURE 6-1. GET AWAY SPECIAL, SMALL SELF-CONTAINED PAYLOADS,
5.0 CU. FT. (NET) CONTAINER

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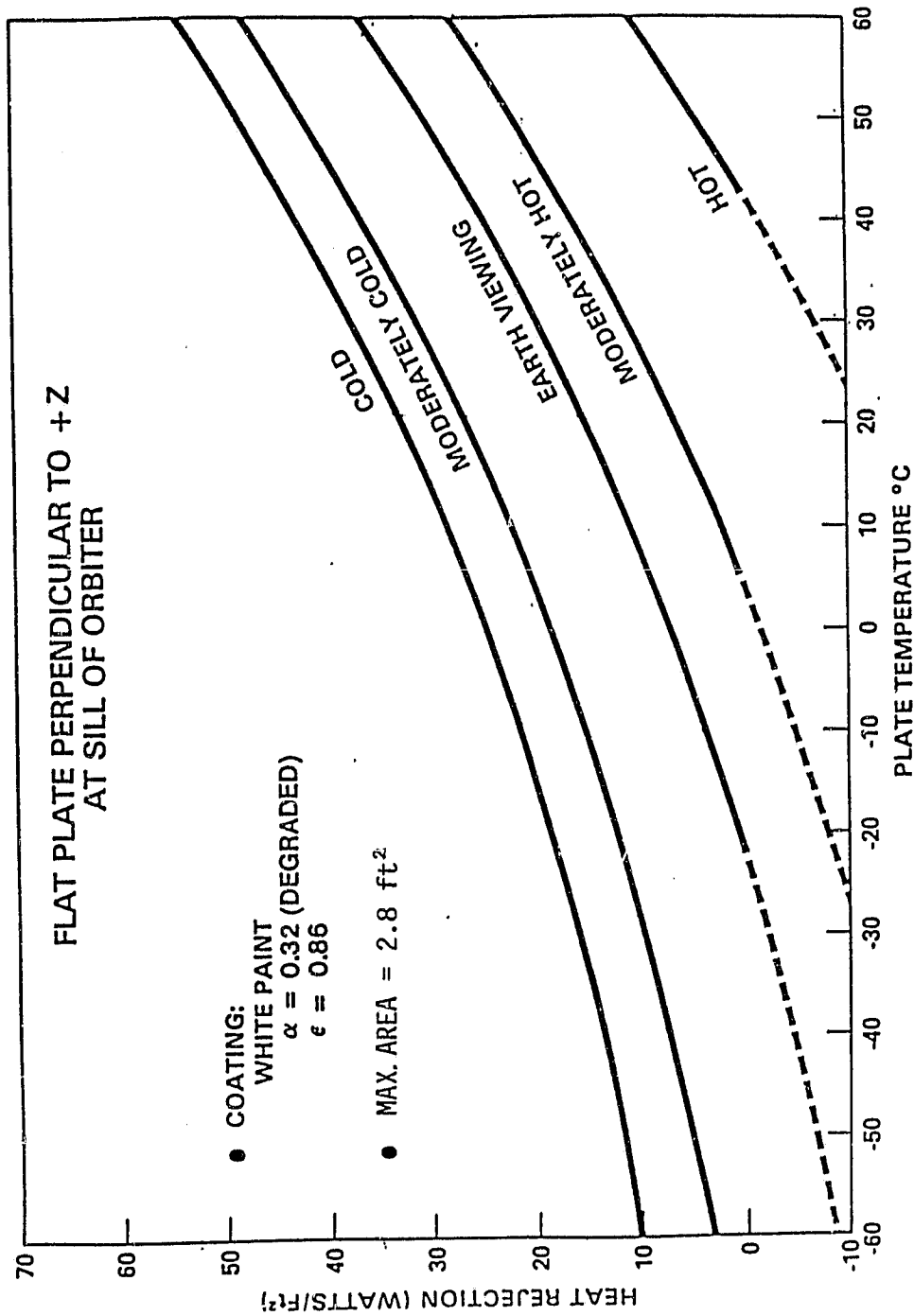
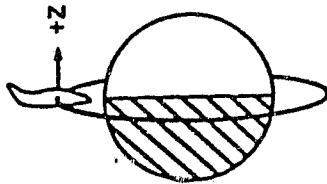


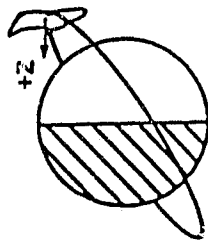
FIGURE 6-2. HEAT REJECTION CAPABILITY

HOI: $\beta = 90^\circ, +Z$ SI



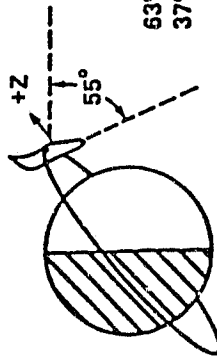
100% SUN

MODERATELY COLD: $\beta = 45^\circ, -Z$ SI



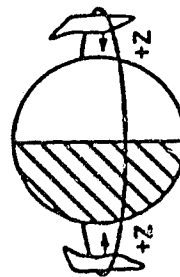
63% SUN
37% SHADOW

MODERATELY HOI: $\beta = 45^\circ$, NOSE DOWN
 55° , SI



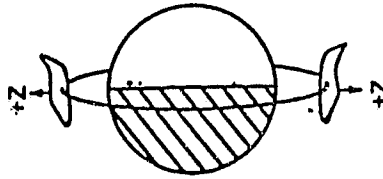
63% SUN
37% SHADOW

EARTH VIEWING: $\beta = 0^\circ, +Z$ LV



59% SUN
41% SHADOW

COLD: $\beta = 90^\circ, -Z$ LV or $-Z$ SI



100% SUN

β = Angle between the orbit plane and ecliptic plane.
SI = Solar Inertial (always pointing at the Sun).
LV = Local Vertical (always pointing at the Earth).
+Z = Axis pointing out of top of payload bay.

FIGURE 6-3. GET AWAY SPECIAL, SMALL SELF-CONTAINED PAYLOADS, ORIENTATIONS USED IN HEAT REJECTION CURVES

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TABLE 6-1. GAS CAN ACCOMMODATIONS

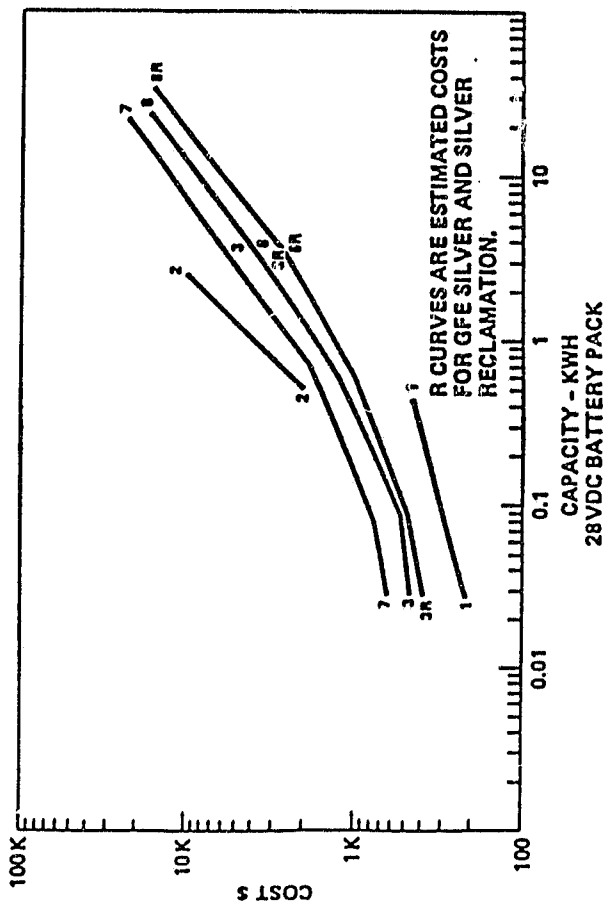
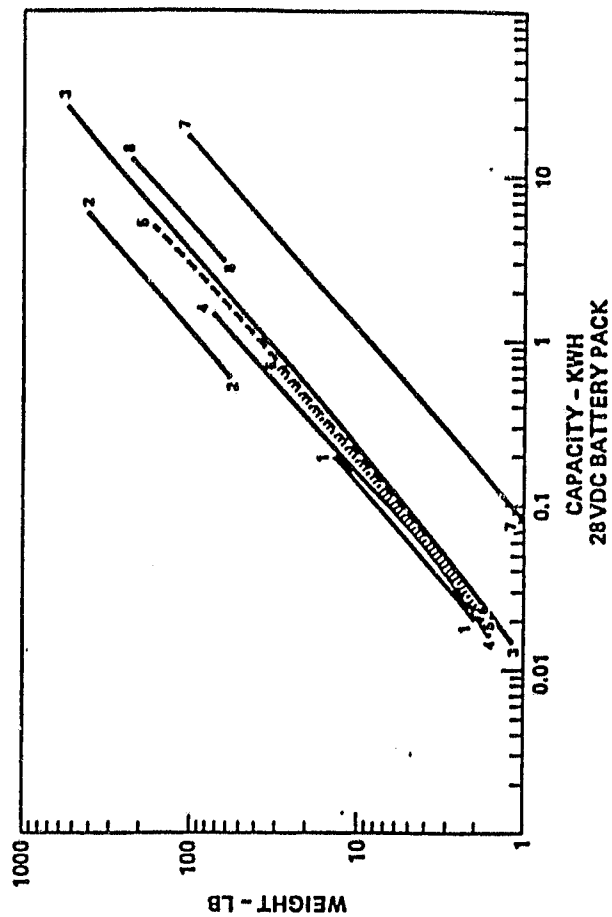
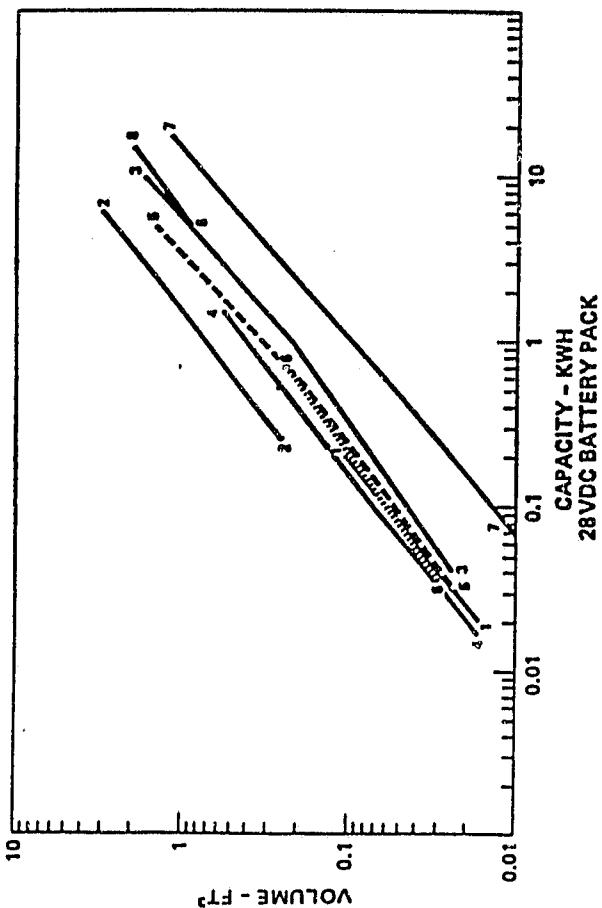
● POWER	NO PROVISIONS
● ENVELOPE	19.75 IN. DIA. x 28.25 IN. HIGH (5 ft ³)
● HEAT REJECTION	100 WATT AVERAGE (ORBIT DEPENDENT)
● ALLOWABLE MASS	200 LB
● DATA	NO PROVISIONS
● CONTROL	3 SWITCHES REMOTELY CONTROLLED BY CREW

TABLE 6-2 GAS ACCOMMODATIONS REQUIREMENTS

SYSTEMS	VOLUME (ft)	WT (#)	HEAT REJECTION REQ (WATTS)
FURNACE	3.0	80	250
ELECTRONICS	1.6	60	150
BATTERIES	2.0*	175*	40
TOTAL	6.6	315	440
GAS CAPABILITY	5.0	200*	100**

*ESTIMATE FROM PAGE 75 GAS EXPERIMENTERS HANDBOOK

**BASED ON MODERATELY COLD ORBIT, PAGE 78 EXPERIMENTERS HANDBOOK



CURVES:

1. SMALL, COMMERCIAL QUALITY NI-CAD BATTERY PACKS.
2. MIL SPEC, AEROSPACE NI-CAD BATTERY PACKS.
3. OFF THE SHELF AG-ZN
4. HI-RATE AG-CAD
5. LO-RATE AG-CAD
6. NI-ZN
7. LI-CF
8. SPECIAL ORDER AG-ZN

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FIGURE 6-4. GET AWAY SPECIAL, SMALL SELF-CONTAINED PAYLOADS, BATTERY DATA

6.3 ACCOMMODATIONS ASSESSMENT

The R&D furnace requirements far exceed the GAS Can capability.

Due to volume/weight limits, it is impossible to install the R&D furnace/electronics/batteries in a single GAS Can (see Table 6-2). The optimum GAS Can/GaAs furnace configuration is shown in Figure 6-5. This concept (requiring GFE batteries, tape recorder) is marginal thermally and would probably require attitude constraints during the mission (violates GAS ground rules).

The Accommodations Summaries are shown for a one GAS Can System, Table 6-3, and for a three GAS Can System, Table 6-4.

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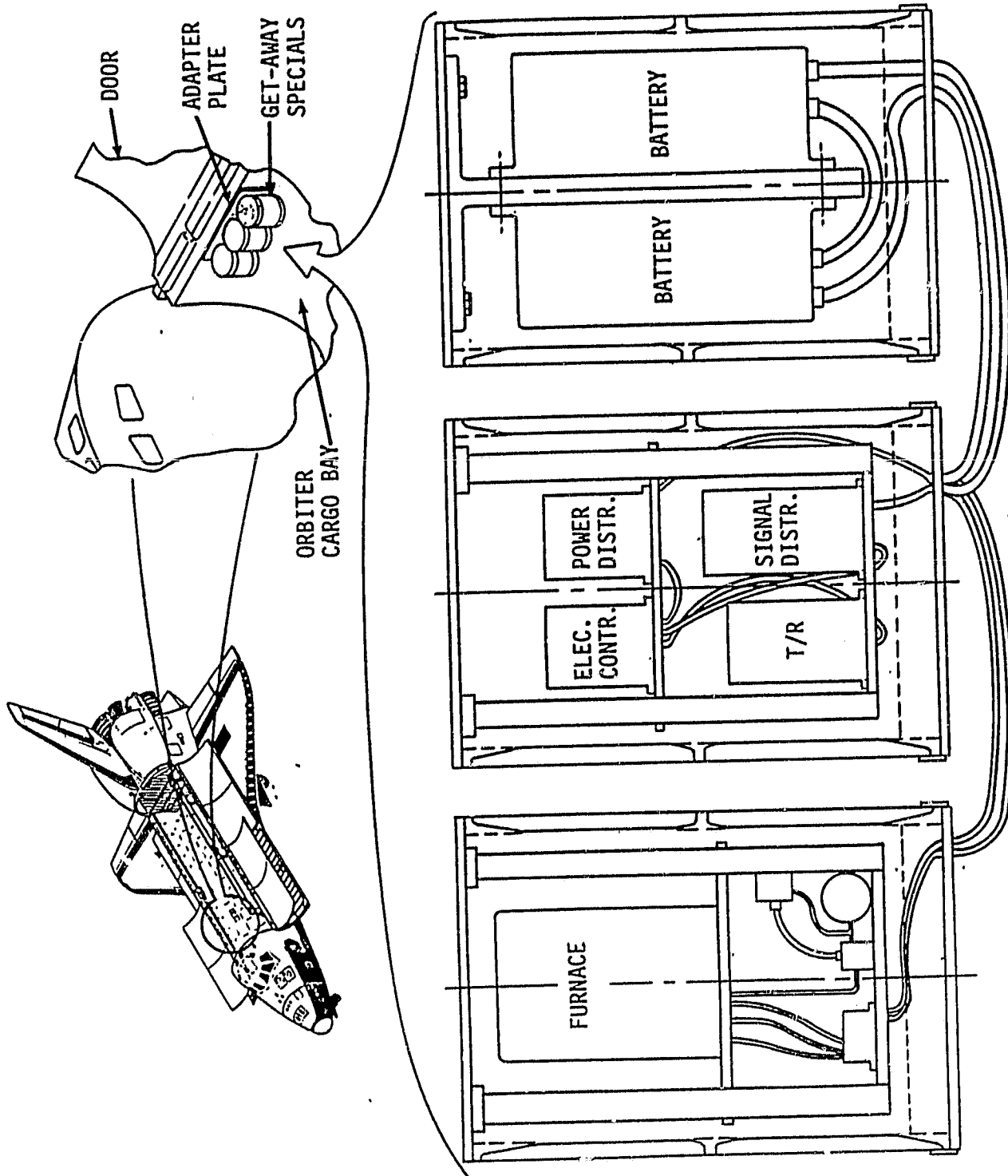


FIGURE 6-5. GAS CAN ACCOMMODATIONS CONCEPT

TABLE 6-3. GAS ACCOMMODATIONS SUMMARY
(ONE CAN)

● CURRENT	}	NO PROVISIONS
● POWER		
● ENERGY		
● HEAT REJECTION		REQUIREMENTS EXCEED CAPABILITY
● MASS		REQUIREMENTS EXCEED CAPABILITY
● ENVELOPE		REQUIREMENTS EXCEED CAPABILITY
● CREW I/F		MINIMUM ACTIVITY
● DATA		NO PROVISIONS
● SAFETY		HAZARDS CAN BE CONTROLLED

TABLE 6-4 GAS ACCOMMODATIONS SUMMARY
(THREE CANS)

● CURRENT	}	GFE OR EXPERIMENT SUPPLIED BATTERIES
● POWER		
● ENERGY		
● HEAT REJECTION		MARGINAL (MAY REQUIRE ATTITUDE CONSTRAINTS)
● MASS		ADEQUATE
● ENVELOPE		ADEQUATE
● CREW I/F		MINIMUM ACTIVITY
● DATA		GFE OR EXPERIMENT SUPPLIED TAPE RECORDER
● SAFETY		HAZARDS CAN BE CONTROLLED

7. CONCLUSIONS

The relative comparison of furnace requirements versus carrier capability for each of the accommodation systems can be seen in Table 7-1.

7.1 MIDDECK

The R&D furnace requirements exceed the Middeck capability in most subsystem areas. Additional power/energy may be negotiable; mission-to-mission. Based on the trade-offs involved in the conceptual design of the facility, it is considered unlikely that the incompatibilities can be resolved by redesign or use of GFE. For example, if the vacuum jacket is enlarged to accommodate additional insulation, envelope and mass problems are encountered. If additional power/energy were utilized, an active cooling system would probably be required.

Therefore, it is recommended the Middeck stowage locker area be eliminated as a candidate carrier for accommodating the R&D furnace facility.

7.2 MEA

The R&D furnace requirements can all be satisfied by the MEA carrier. Even though furnace data requirements have not been established, the MEA Data Management System is adequate for all but very extreme requirements.

The MEA is a viable carrier for the R&D facility, and MEA/furnace interface definition should proceed as process/experiment requirements mature.

7.3 GAS

The R&D furnace requirements exceed the one GAS Can configuration in all subsystem parameters. Neither furnace redesign nor the use of GFE would allow the packaging of the furnace, electronics control and conditioning, data system, and power supply within one GAS Can.

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TABLE 7-1. ACCOMMODATION SUMMARY

CAPABILITY REQUIREMENTS				
	MIDDECK	MEA	GAS (1)	GAS (3)
CURRENT	NO	YES	NO	YES *
POWER	NO	YES	NO	YES *
ENERGY	NO	YES	NO	YES *
COOLING	NO	YES	NO	MARGINAL
MASS	MARGINAL	YES	NO	YES
ENVELOPE	MARGINAL	YES	NO	YES
DATA	NO	YES	NO	YES *
SAFETY	MARGINAL	YES	MARGINAL	YES

YES - CAPABILITY EXCEEDS REQUIREMENTS

NO - REQUIREMENTS EXCEED CAPABILITY

* - GFE OR EXPERIMENT SUPPLIED BATTERIES AND DATA SYSTEM

The R&D furnace requirements can all be satisfied (cooling marginal) by the three GAS Can configuration. This option would require the development of Lithium type batteries within the weight and volume constraints of a GAS Can. This development requirement alone (battery development/qualification normally long and costly) greatly detracts from this option, however, program groundrules eliminate it. Information from D. Miller, NASA Headquarters GAS manager, and C. Prouty, GSFC GAS manager - an experiment must be packaged within one GAS Can.

Therefore it is recommended both the one GAS and the three GAS configurations be eliminated as candidate carriers for accommodating the R&D facility.

7.4 MICROGRAVITY REQUIREMENTS

The acceleration requirements for the experiment/process are presently defined as being 10^{-5} g's. However, the understanding is that this requirement is not based on any direct analyses or experiments for the proposed process, but rather this level is an educated guess with some inputs from Skylab experience. Therefore, the actual microgravity requirements are TBD and must be regarded as an open item for the program.

In terms of accommodations, the attainable acceleration/gravity levels will be influenced by the accommodations location relative to the center of gravity of the orbital configuration. Thus, there will be differences in the Middeck and Cargo Bay in this respect (and differences at differing positions in the bay).

The Orbiter is cited in Reference 6 as having capabilities below 10^{-4} g's for quiescent operations. However, it is not considered reasonable to expect such operations for periods of time extending in days. This expectation is derived from MEA-A planning for which it was found to be advantageous to schedule the one hour of 10^{-5} g's for the Acoustic Levitator on a contingency basis.

The conclusion is that the status of the requirement is too immature to permit any assessment other than the achievable acceleration/gravity levels versus the stated requirements are a major concern.

7.5 SENSITIVITY

The levels of maturity of the requirements of the process/experiment of the facility design have been a concern throughout the study in that the results obtained are direct functions of these requirements. However, the very negative results obtained from both the Middeck and GAS Can suggest that improvement by furnace redesign or by GFE is far beyond reasonable expectations. Also, the results are not judged to be dependent to any significant extent on any one of the requirements imposed. Two areas of uncertainty, acceleration and data requirements, are not determining factors.

C - 2

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